AIR SERVICE HANDBOOK

VOL. I

AVIATION SECTION
SIGNAL CORPS

AIR SERVICE HANDBOOK

VOL. 1

AVIATION SECTION, SIGNAL CORPS

INTENTION OF BOOK

The contents of this manual have been copied from various works, and the chapters which apply have been reproduced word for word

It is intended that it should be given to every pilot, and that a number should be available for mechanics

The handbook should be sufficient for elementary training in rigging, engines, instruments, magnetos, meteorology and theory of flight, so that pupils need not read books which are not useful or which cover the same ground, in other words

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The following Air Service handbook, A Course of Instruction for Pilots and Mechanics, prepared in the Office of the Chief Signal Officer, is approved and published for the information and guidance of the Schools of Military Aeronautics.

(A. G. O.—No. 062.1.)

BY ORDER OF THE SECRETARY OF WAR.

D. W. KETCHAM,
Colonel, General Staff.

OFFICIAL:
H. B. McCAIN,
The Adjutant General.

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AIR SERVICE HANDBOOK.

I. GENERAL RULES.

THE GENERAL ROUTINE IN A HANGAR.

Because the endurance and air worthiness of aircraft largely depends upon the care which is spent upon them, they should be well looked after when in the hangars. Airplanes should not be exposed to extremes of heat and cold. However well seasoned wood may be, if it is allowed to absorb moisture it will invariably deteriorate. Hangars therefore should be kept dry and, as far as possible, at an even temperature.

Cleanliness.—An airplane can never be too clean. Rust, mud, dirt, and superfluous oil should be at once removed when the machine returns to the hangar.

Supports.—Further, an airplane once housed must have its weight supported in such a manner that there is no strain on the shock absorbers. The tail should also be supported so that there is not a continual strain on the fuselage. In this connection it must be remembered that supports should be so placed and in such a position that the main weight of the machine is directly over them. The best position is immediately under the points where the landing gear struts meet, or meet the longerons. In case it is necessary to support the wings or tail, the support should be under struts; in the case of the wings, under the interplane struts nearest to the fuselage.

Inspection.—Before an airplane proceeds on a flight and after its return all parts—such as control and aileron cables, dope, places where cables cross, the longerons, etc.—must be thoroughly examined and the least sign of wear in any part must be at once corrected. It is important to watch the wear of control wires at points where they pass over pulleys or fairleads. For efficient inspection the machine must be cleaned, oil and grease must be removed before the cables can be properly seen. The mere fact of cleaning a machine insures that every part has at least been looked at.

All engines must be thoroughly tested before flying and after any repairs or overhauling has been effected. Once a week, at least, a thorough routine examination must be made of all struts, internal

bracing wires of fuselage, etc., with a view to checking any damage or want of alignment. If an airplane makes a forced descent and has to be left in the open it is important to guard against possible contingencies, and it should be looked after as described under "Cross country flying."

The planes of a machine must be cleaned directly after a flight, to prevent the oil and dirt soaking into the machine. Oil deteriorates wood and the machine may therefore lose its factor of safety.

At the end of a hundred hours' flying, the machine should be inspected by the engineer officer, who may or may not allow it to be flown farther.

Any repairs necessary to a machine should be done at once, as a machine is often wanted in a hurry

Tires of machines are injured by oil and grease. No oil therefore should be allowed to collect on the floor of the hangar.

Hangar floors.—Floors of hangars may be kept clean by the application of hot water and caustic soda. In this connection, it should be remembered that caustic soda rots leather boots so that wooden clogs should be used by the men engaged in this work. Sawdust must not be allowed as it accumulates dirt. Sawdust and old rags which have become oily are liable to spontaneous combustion if they are left in the sun or near the sides of a corrugated iron building. Sawdust is only permissible in a tray in order to catch the waste oil from the engine.

Engine stands.—Stands should be provided for engines to rest on when they are taken out of airplanes.

Clothing.—Pegs should be provided for aviation clothing and helmets and also for the mechanician's coats, which are changed for overalls when the men come to work. No clothing should be allowed to lie about.

Fire.—Owing to the inflammable nature of an airplane building and the large value of the articles kept in it, every precaution must be taken against fire. Fire drill should be held periodically. Buckets of sand and water must be kept completely filled in convenient places in each hangar. At least one fire extinguisher, such as "Pyrene," should be kept in each hangar ready for use, and all men should know how to use this apparatus.

Notice board.—A bulletin board should be provided in the hangar of each section on which orders, etc., should be posted.

Spares.—Only the authorized spares may be kept in the hangars. The tendency to accumulate unauthorized parts must be checked. Care must be taken that spare parts, where applicable, are kept properly oiled or greased to prevent them rusting. Every part must bear a label, showing exactly what it is and to what it belongs.

No mechanician should be allowed the opportunity of making a private collection of spare parts for use in effecting repairs. Pigeon holes should be provided for engine parts and various small stores, which should be labeled. When drawing new parts from the supply room the mechanician should, as a general rule, and if possible, hand in at the same time the corresponding broken parts. Condemned parts should be clearly marked and kept in a special place, so that there is no possibility of their being used again by a careless workman. Spare planes should be stored in such a manner that their weight is evenly supported. One plane must not be allowed to butt into another. It has been found best to suspend planes by means of canvas slings hung from overhead. Within the loop of the slings there must be a wooden batten about 2½ inches wide, so that the leading edge of the plane is supported the whole way along.

Records.—Rough records should be kept in each section in which all details of flights, overhauls, expenditure, fuel, and oil, etc., are entered whenever each event occurs and are of assistance in making the record an accurate history of the airplane and engine. Log books must invariably be made up to date, signed and forwarded at the same time as an engine or airplane is transferred from one unit to another.

Smoking.—Smoking in the hangar is strictly prohibited.

GENERAL ORGANIZATION OF THE WORKSHOP.

Personnel.—The personnel available should be divided into three separate departments, with a master signal electrician in charge of each. A commissioned officer should exercise general supervision over each department.

The three departments are:

(*a*) Aero repair shop.
(*b*) Dope shop.
(*c*) Machine shop.

It is desirable that the airplane and dope work be conducted in a separate building from the engine and machine work.

Care.—All mechanicians must be made to realize that the greatest care and attention to the minutest details is absolutely necessary.

Bench.—Where airplane hangars or workshops are provided with benches and vises it is convenient that the benches be fitted with lock-up drawers for the storage of tools.

Benches must not be allowed to become mere shelves for the assortment of rubbish, spare parts, and discarded breakages. No article should be kept on a bench close to where some particular work is on hand which has not a direct bearing on that work. Boxes should be provided in which metal such as brass or steel fittings

may be kept. At regular intervals, not less than once each week, all rubbish must be removed.

Tool boxes.—Places should be allotted for the mechanics' tool boxes, and their contents should be periodically inspected. A list of the correct contents of the box should be pasted inside the lid.

Care of machinery.—Only the mechanics authorized by the engineer officer should be allowed to use the lathes, saws, etc., with which the shops are provided and to start the motors for driving these machines.

With electrically driven machinery care must be taken that all switches are "off" before the shops are closed at the end of the day. Lathes, etc., and their accessory parts must be kept properly oiled and greased and free from rust. All belting must be provided with suitable guards. All flat-faced surfaces in lathes should be suitably protected by wood to prevent them from being damaged by tools falling on them. All shavings, sawdust, and metal turnings must be cleared away from the machines daily. The metal turnings should be preserved for future use or sale, different metals being kept separate.

Examination and dismantling of airplanes.—This work, if it is made a matter of routine, is simple and occupies a small amount of time. The following is the system which has been found most suitable:

(*a*) In the case of serious damage or periodical overhaul the airplane must be taken at once to the shops by the men of the section to which it belongs.

(*b*) The engineer officer then carries out his detailed examination and prepares a statement setting out in detail the general condition of the machine.

(*c*) The airplane is then stripped and all parts labeled.

(*d*) In all cases in which the machine has been in an accident the engine must be removed for a thorough examination and overhaul. For this purpose it must be turned over to the machine shop.

(*e*) The parts which are not repairable are removed to the authorized place and all small stores, such as turnbuckles, bolts, etc., which are apparently still serviceable are handed into the shop stock room. In the stock room they are kept separate from the other spares until they have been pronounced serviceable or otherwise by the officer in charge.

(*f*) The parts which can be repaired and made fit for service are labeled and sent to the department concerned where they will await their turn for repair.

(*g*) The undamaged parts are handed into the stock room properly labeled. These should be taken on temporary charge as spares in

the workshop store, until the airplane is again ready for them. If the airplane can not be repaired the undamaged parts must be taken on permanent charge in the store account of the unit.

(*h*) All instruments requiring repairs should be returned to the stockroom and the engineer officer should decide whether the instruments are to be returned to the makers for repair or not.

(*i*) All parts repairable or sound should be thoroughly cleaned before being turned over to the supply officer.

(*j*) Parts of airplanes while awaiting erection must be properly supported or stored. When the airplane is being erected all parts intended for that particular machine must be kept together so as to avoid using wrong parts.

Engine repair work.—A system must be established and worked on whenever an engine is taken down for repair and reassembled.

Suitable stands must be provided on which to place engines.

Trays divided up into compartments in which to put each part of the engine as it is removed are a necessity. It is a good thing to have each compartment numbered and the parts of each cylinder and its attachments put into the compartment corresponding to its number in the engine. A little shelf can conveniently be constructed on the outside of these compartments on which to lay the tools so as to prevent them getting lost or dirty.

Only in cases of urgency should parts of one engine be used to complete another. If such a course is necessary the parts so used should be numbered afresh so as to correspond with the numbering of the engine in which they are used. Thus, if "number 5" piston of one engine is to be used as "number 7" in another, it should be renumbered "number 7."

When reassembling an engine the utmost care is necessary to insure that all parts are free from grit and dirt. Gasoline baths are a necessity.

Every part should be thoroughly oiled before being replaced.

Any metal part which has been bent should on no account be straightened and replaced in the engine without the knowledge of the engineer officer. As a general rule such bent parts must *not* be straightened and used again.

When the engine has been overhauled and tested it should bear a label showing date of test, time run, and number of revolutions obtained. It should then be put to one side and greased pending a necessity arising for its use in an airplane.

Engines must be turned daily by hand.

Logbooks must be kept, made up to date, showing work done on the engine and these books must always accompany the engines.

The care of tools.- Protect all edges. Keep all edged tools sharp. If you dull a tool by using it sharpen before returning it to its place.

In sharpening an edged tool do not blunt it. Grind an angle and keep it until the tool becomes sharp. If you round off an edged tool you ruin it.

Do not use a file like a hack saw, as most files are made to cut on the forward stroke only. Keep files in a case where they do not rub against each other and keep them free from oil and grease. When using a file always put a handle on it. Have a file cleaner handy and use it often.

For a fine finish on steel do not use a file, use an oilstone.

Do not keep soldering acid near tools nor handle tools after using acid without first washing your hands.

Have your list of tools pasted in the top of your chest and check your tools each evening before quitting.

Keep bits sharp and in a case and do not expect to drill a true hole with a dull bit.

Do not use a steel hammer on metal parts, use a brass or rawhide hammer, or copper or brass drift.

Oil your tools often in rainy or wet weather.

Do not keep sulphur or salt near your tools.

Always oil the steel tape before putting it away.

Do not use a monkey wrench as a hammer.

Do not use a screw driver as a punch, drift, or lever, and keep the sides of the point parallel.

Do not use pliers on nuts. Do not use a 24-inch monkey wrench on a quarter-inch nut. Do not use an end wrench on a nut unless it fits properly. The same remark applies to all wrenches on nuts, and to screw drivers on screws.

Keep your fine measuring tools in a case.

Do not hold work that is being heated with a torch with a pair of pliers: use regular tongs.

Use only regular nippers for cutting piano wire. The ordinary side-cutting pliers are usually not strong enough for this.

In using a tap always be sure that the right size hole has been drilled. In using taps and dies use plenty of lard oil on the work and be careful of backing up the tap or die. Always read instructions furnished by the manufacturer. In cutting large, heavy stock it is better to take more than one cut. Always clean taps and dies before putting them away.

Do not use a Stilson wrench on nuts.

Sharpen your tools over all the surface of an oilstone and not only in one place.

Always keep the cutting edge of your saw well protected.

It is useful to have a place for each tool so that they can not shift when the boxes are put on the motor transport in a hurry.

Each mechanic is advised to keep a memorandum book in his possession in which he may record such notes as may be considered useful to him.

II. RIGGING.

RUDIMENTS OF FLIGHT AND STABILITY.

In order that a pilot may take an interest in the rigging of his machine he should have a sound idea of the rudiments of flight and stability. He need not know how to design a machine, as this is a highly technical procedure which is done by the machine designers. The pilot should know how to fly any machine he is given to the best advantage.

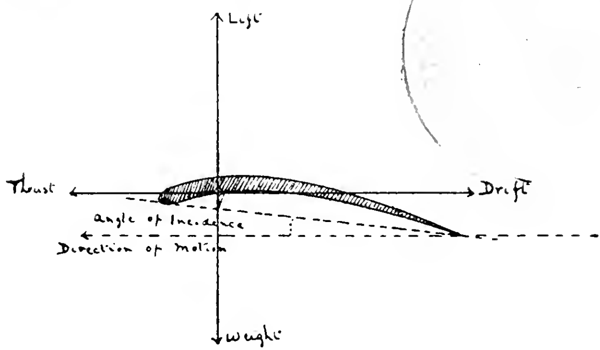

FIG. 1.

Flight is secured by driving through the air a surface or surfaces inclined to the direction of motion. The surface meeting the air tends to drive the air downward and this causes a resultant reaction on the surface. The resultant acts approximately at right angles to the plane or, if the plane is curved, to the chord.

The total reaction on the aerofoil can be considered as made up of two forces, one acting in a vertical direction and one in a horizontal.

Lift.—The lifting planes by being driven through the air secure a lift, and when the speed is great enough the lift will become greater than the weight of the airplane, which must then rise. Thus, the vertical part of the total reaction on the plane is called "Lift." Bear in mind that the lift is always trying to collapse the planes upward.

Drift.—The resistance of the air to the passage of an airplane is known as "Drift." Thus, the horizontal part of the total reaction

on the plane is called "Drift." This is overcome by the "thrust" of the propeller, which thrusts the airplane (or drags it) through the air and so overcomes the drift. Bear in mind that the drift is always trying to collapse the planes backward.

You will see from the above diagram that there are four forces to consider. The lift, which is opposed to the weight, and the thrust, which is opposed to the drift. The lift is useful; the drift is the reverse of useful. The proportion of lift to drift is known as the "Lift-drift ratio." This is of paramount importance, for upon it depends the efficiency of the airplane. In rigging an airplane the greatest care must be taken to preserve the lift-drift ratio. Always keep that in mind. This means that the lifting planes of a machine must not be damaged, that the adjustments of the machine are exactly in accordance with the rigging diagram, and that all work is done neatly and carefully.

Angle of incidence.—The angle of incidence is the inclination of the lifting surfaces. If the angle of incidence is increased over the angle specified in your rigging instructions, then both the lift and drift are increased also, and the drift is increased in greater proportion than the lift. If, however, the angle of incidence is decreased, then the lift and drift are decreased and the lift decreases in greater proportion than does the drift. You see then that in each case the efficiency is spoiled, because the proportion of lift to drift is not so good as would otherwise be the case.

Balance.—The whole weight of the airplane is balanced upon, or slightly forward of, the center of the lift.

If the weight is too far forward, then the machine is nose heavy.

If the weight is too far behind the center of the lift then the airplane is tail heavy.

In either case an adjustment must be made which spoils the efficiency of the machine.

Stability.—By stability of the airplane is meant the tendency of the airplane to remain upon an even keel and to keep its course; that is to say, not to fly one wing down, tail down, or nose down, or to try and turn off its course.

Directional stability.—By directional stability is meant the natural tendency of the airplane to remain upon its course. If this did not exist, it would be continually trying to turn to right or to left, and the pilot would not be able to control it.

For the airplane to have directional stability it is necessary for it to have, in effect, more keel surface behind its turning axis than there is in front of it.

By keel surface is meant everything you can see when you look at the airplane from the side of it—the sides of the body, landing

gear, wires, struts, etc. Directional stability is sometimes known as "weather-cock stability."

If in the case of the "weather cock" there was too much keel surface in front of its turning axis, which is the point upon which it is pivoted, it would turn around the wrong way; and this is just what would happen in the case of the airplane.

Directional stability will be badly affected if there is more drift (i. e., resistance) on one side of the airplane than there is on the other. This may be caused by the following:

1. The angle of incidence of the main planes or the tail plane may be wrong. If the angle of incidence on one side of the machine is not what it should be, that will cause a difference in the drift between the two sides of the airplane, with the result that it will turn off its course.

2. If the alignment of the fuselage or fin in front of the rudder or the stream-line struts is not absolutely correct, that is to say, if they are turned a little to the right or left instead of being in line with the center of the machine in the case of the fin and dead on in the direction of flight, they will act as an enormous rudder and cause the machine to turn off its course.

3. If the dihedral angle is wrong that may have a bad effect. It may result in the propeller not thrusting from the center of the drift, in which case it will pull the machine a little sideways and out of its course.

4. If the struts and stream lines on the wires are not adjusted to be dead on in the line of flight, then they will produce additional drift on their side of the airplane, with the result that it will turn off its course.

5. Distorted surfaces may cause the airplane to be directionally bad. The planes are "cambered"; that is, curved to go through the air with the least possible drift. If perhaps owing to the leading edge spars or trailing edge getting bent, the curvature is spoiled, with the result that the amount of drift on one side of the airplane is altered, causing the machine to have a tendency to turn off its course.

Lateral stability.—By lateral stability is meant the sideways balance of the machine. The only possible thing that could make the machine fly one wing down is that there is more lift on one side than there is on the other. This may be due to—

1. The angle of incidence may be wrong. If the angle of incidence is too great, it will produce more lift on that side than on the other. The result will be that the machine flies one wing down. This remark also applies to too little incidence on one wing.

2. Distorted surfaces: If the planes are distorted, then their camber is spoiled and the lift will not be the same on both sides of the airplane.

3. If stability is not horizontal, it will cause a twisting movement.

Longitudinal stability.—By longitudinal stability is meant the fore-and-aft balance. If this is not correct, the machine will try to fly nose or tail down. This may be due to—

1. The stagger may be wrong. The top plane may have drifted back a little, and this may be due to some of the wires having elongated their loops or having pulled the fittings into the wood. If the top plane is not staggered forward to the correct degree, it means that the whole of the lift of the airplane is moved backward, so that it will have a tendency to lift the tail; that is, it will become nose heavy. A quarter inch error in the stagger makes a considerable difference.

2. If the angle of incidence of the main planes is too great, it will produce an excess of lift, which will tend to lift the nose of the machine. If the angle is too small, the opposite happens.

3. When the machine is longitudinally out of balance the usual thing is for the rigger to rush to the tail plane, thinking that its adjustment relative to the fuselage must be wrong. This is the least likely reason. It is much more likely to be one of the first two, or, more probable still, that the fuselage has warped upward. This gives the tail plane an incorrect angle of incidence. This is due to bad landings or to allowing the machine to rest in the hangar with its its tail on the ground, so that it always has a certain amount of weight on it and it gets no rest.

4. If the above three points are correct, there is a possibility that the tail plane itself has assumed a wrong angle of incidence. In such event, if the machine is nose heavy, the tail plane should be given a smaller angle of incidence. If the machine is tail heavy, then the tail plane must be given a large angle of incidence, but *be careful not* to give the tail plane too *great* an angle of incidence. The longitudinal stability of the airplane entirely depends on the tail plane being at a much smaller angle of incidence than the main plane, and if you cut the difference down too much the machine will become uncontrollable. Sometimes the tail plane is set on the machine at the same angle of incidence as the main planes, but it actually engages the air at a lesser angle, owing to the air being deflected downward by the main planes.

Propeller torque.—Owing to propeller torque, the airplane has a tendency to turn over sideways in the direction opposite to that in which the propeller revolves. In some machines this tendency is rather marked, and this is offset by increasing the angle of incidence on the side tending to fall and by decreasing the angle of incidence

the same amount on the side tending to rise. In this way more lift is secured on one side of the machine than on the other, so that the tendency to overturn is corrected.

Wash in.—When the angle of incidence toward the tip of the main plane is increased the plane is said to have wash in.

Wash out.—When the angle of incidence is decreased it is called wash out.

Sometimes wash out is given to both sides of a main plane. This decreases the drift toward the wing tips, and consequently decreases the effect of gusts upon them. It also renders the ailerons more effective.

Importance of good rigging.—It is impossible to exaggerate the importance of care and accuracy in rigging. The lives of the crew, the speed and climb of the airplane, its control and general efficiency in flight, and its duration as a useful machine all depend upon the rigger. Consider that while the engine may fail, the pilot may still glide safely to earth; but if the airplane fails, then all is lost. The responsibility of the rigger is therefore very great, and he should strive to become a sound and reliable expert on all matters relating to his art. For an art it is, and one bound to become increasingly important as time passes.

GENERAL RULES FOR RIGGING.

There are two kinds of machines—the tractor and the pusher. The pusher type is a type which is now dying out. The principles of rigging for both are the same. The different steps of rigging are as follows:

1. Get a blue print or rigging diagram of the machine and look at the essential measurements.
2. True up the fuselage and fix the tanks and internal fittings.
3. Put on the undercarriage (landing gear), in order to insure that the machine can not fall.
4. Rig, fix, and true up the center sections of the main planes.
5. Rig the main planes separately.
6. Attach and true up the main planes.
7. Rig tail (separately, if necessary). Fix and true up.
8. Attach balancing surfaces and adjust controls.
9. Check all measurements and see that every pin, nut, etc., is locked.
10. Put engine in machine.
11. Look over the whole machine to see if everything is correct.

Before starting work on a machine, get into overalls, because a man can not do proper work if he has to think of his clothes. See that all the necessary tools are handy. Sort and lay out the planes,

struts, cables, etc., putting each more or less in its relative position (if there is sufficient room in the shed).

The useful tools are as follows:

1 side-cutting pliers.
1 round-nose pliers.
1 small three-cornered file (to ease burrs on bolts and pins).
1 hammer (to be used only when absolutely necessary) and copper or brass drift.
1 carpenter's level.
4 plumb bobs.
1 carpenter's rule.
1 straightedge about 3 feet long.
1 long and 1 short tramel.
1 steel measuring tape.
1 ball of string.
2 turnbuckle keys.
2 pairs auto combination pliers, *not for nuts or bolts.*
Spanners suitable to the bolts and nuts on machine.
End wrenches suitable to the bolts and nuts on machine.
See that split cotter pins, nuts, and bolts, etc., are handy.

Truing up the fuselage.—In factories the longerons of the fuselage are clamped onto a table which has blocks on it shaped as required. In the field the rigging has to be done by measurement from the beginning. It is unusual in the field for the squadrons to have to rig a fuselage, but it may often be necessary to true it up. Before attaching any wires to the fuselage, all metal fittings should be attached in the proper places on the longerons. All struts should be fitted in their sockets in order to prevent delay in assembling. The two sides of the fuselage are trued up first, and it is usual either to make the top longeron straight or to make the whole tail symmetrical. This must be found out from the blue print. When each side has been trued up, the horizontal compression members can be placed between the two sides and the bracing and the internal cross bracing of the fuselage can be adjusted. While doing this the fuselage should be supported on two trestles; the first trestle should be toward the front and the rear trestle about two-thirds of the way toward the rear. This causes the tail to stick out unsupported and will give strains on the fuselage nearly the same as those put on the machine in flight. The bracing of a fuselage is done by means of cables, piano wire, or special tension bars. These are adjusted in different ways, as will be explained later.

The engine beds are usually adjusted permanently as far as we are concerned, and it is only necessary to see that the remainder of the fuselage is trued up properly with respect to these.

When the fuselage has been itself trued up, it is then necessary to put it in the flying position; that is, the engine beds must be horizontal and the horizontal compression members should be also horizontal. This is done by placing a straightedge and spirit level on the engine foundations, and you must be very careful to see that the bubble is exactly in the center of the level. The slightest error will be much magnified toward the tail and wing tips. Great care should be taken to block the machine up rigidly. In case it gets accidentally disturbed during the rigging of the machine, you should constantly verify the flying position by running the straightedge and spirit level over the engine foundations. Carefully test the straightedge before using it, for, being usually made of wood, it will not long remain true. Place it lightly in a vise and in such a position that a spirit level on top shows the bubble exactly in the center. Now slowly move the level along the straightedge. The bubble should remain exactly in the center. If it does not, then the straightedge is not true and must be corrected. Both top and bottom should be true and exactly the same distance apart. Never omit testing the straightedge. In the case of the airplane fitted with engines of the

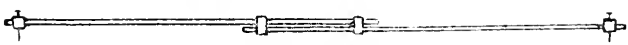

FIG. 2.

rotary type the "flying position" is some special position laid down in your rigging diagram and great care should be taken to secure accuracy.

The easiest way of measuring the length of a wire is by means of a tramel. This is a piece of wood which carries spikes at each end—one is fixed, and the other is adjustable.

If necessary, the wires and turnbuckles should now be locked and painted.

Put the tanks in the machine and fix all the internal fittings. It is easy to get at the inside of the fuselage now, but when the wings are on or when it is covered with dope this will be very difficult.

THE PLANES.

The planes, both main, center section, and tail, and all control surfaces consist of spars and ribs covered with dope. If the surface is large, they are braced internally with wires, cables, or compression members. The wings consist of two spars, the front and the rear, which are kept apart by compression ribs and kept in shape by bracing wires, which are fixed to the ends of the ribs, diagonally opposite and sometimes by diagonal ribs. The bracing thus consists of a number of rectangles, usually two or three in number. To true

up. place the front and rear spar on trestles which are the same height Attach all metal fittings to the spars. Build the compression ribs onto the spars, and fix and tighten up the cross-bracing wires. Make certain that these wires are of the same length by means of the tramel. Look along both spars and see that they are straight.

The spars are always made of ash or spruce, usually spruce. The compression ribs are usually made of solid spruce or some such material or in box form. They are sometines steel tubes. They fit into sockets, clipped around the spar. The main spars should not, as a rule, be drilled to take fittings as they are thereby weakened. On no account should a spar be pierced in a place not shown on the construction diagram. The bracing wires are attached to steel clips called wiring plates and are adjusted by turnbuckles.

The leading edge of a plane is not meant to take any appreciable load and consists of some light wood rounded off in front. The

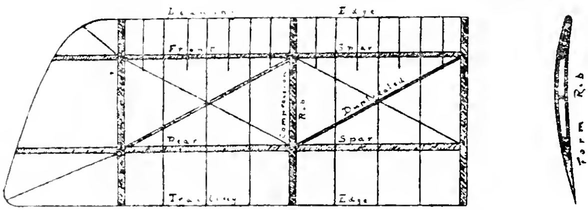

Fig. 3.

trailing edge has no thickness and consists usually of a thin piece of wood or wire stretched from rib to rib in order to support the fabric. Form ribs run from the leading to trailing edge at intervals of about 18 inches. These are only to support the fabric and are usually made of three-ply wood. Holes are bored in these ribs to lighten them. Between the leading edge and the front spar are a number of light form ribs to enable the fabric to keep its shape. In some machines these ribs are replaced by a layer of three-ply wood. A rib consists of a web with a flange on the top and bottom. The fabric is tacked onto the center of these flanges so that the tack passes down the web of the rib. Or better still, the fabric is sewn onto these ribs. It is always a bad practice to pierce wood if there are other ways of doing the job. When the wing has been trued up and all bolts, etc., locked, it may be covered with fabric, dope, and varnish, as described later. All metal fittings are now attached to the planes.

The center section.—Place the center section struts in the sockets on the center section and attach the bracing wires. Lift the whole of this unit and place the bottom of the struts into their sockets on

the fuselage. True up this center section. The machine may or may not have stagger. If it has not, the front center section struts will be vertically over the struts in the fuselage. This may be adjusted by dropping a string with plumb bob attached from the wing attachment of the front spar, seeing, first of all, if the plumb bob falls immediately over that of the lower plane. If it does not, alter the incidence wires. Then hold the string in front of the center section and see if the struts are upright. If they are not, alter cross-bracing wires. If the machine has stagger, the plumb bob must fall a certain number of inches in front or behind the attachment for the lower plane, and this amount will be found from the blue print. In some machines the struts are splayed outward from the fuselage. In any case, they will be symmetrical and the adjustments can be made by measuring the cross-bracing wires, and seeing that they are equal. *Make certain that the adjustment of the center section is correct, because on this depends the whole adjustment of the machine.*

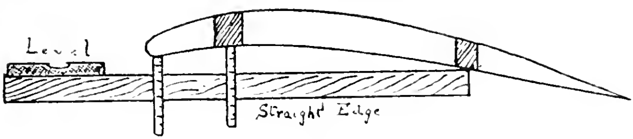

FIG. 4.

The wings.—Make certain that the fuselage is in the flying position. Place trestles on either side of this so that when the wings are lifted they can be rested on these trestles in approximately the flying position. The wings on each side of the machine are rigged separately. This is done by supporting the planes on the leading edges, care being taken that the leading edge is not damaged. The struts are fitted into their proper sockets and the bracing wires are adjusted to their approximate length so that the whole pair of planes may be lifted as a unit. Attach the wings to the center section and fuselage. When the planes are on each side, take away the trestles and allow the strain to come onto the landing wires.

True up the main planes by adjusting these landing wires-making certain that all the other wires are sufficiently loose so as to take no strain. The wings should be symmetrical, the corresponding wires on either side being equal. The incidence should be that shown in the blue print and the dihedral angle is shown there also.

To measure the incidence.—One method of finding the angle of incidence is as follows:

Take the straightedge and test it. Place one corner of the straightedge underneath and against the center of the rear spar, holding it in line with the ribs. Put a level on the end which sticks out from the

plane and hold the straightedge horizontal. Measure from the straightedge to the center of the bottom of the front spar or to the lowest part of the leading edge. Make the measurement that shown in the blue print by altering the landing wires. See that the spars are straight while this is being done. Check the measurements under each set of struts. If the machine is being adjusted after having been rigged, slacken off all wires going to the top of the strut concerned and then tighten all wires going to the bottom, or vice

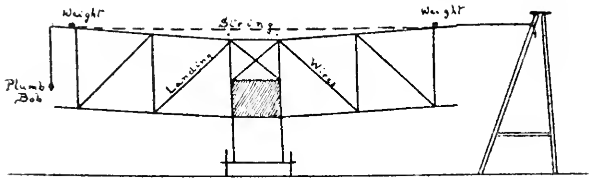

FIG. 5.

versa. Do not attempt to secure this adjustment by merely altering the incidence wires. This latter is a very bad practice indeed, and while, owing to the airplane being of such flimsy construction, it may be possible to change the angle of incidence by adjusting merely the incidence wires, the result of such practice is to throw other wires into undue tension, which will cause the framework to become distorted.

The dihedral angle.—One method of securing the dihedral angle, which is the upward inclination of the wings toward their tip, is as

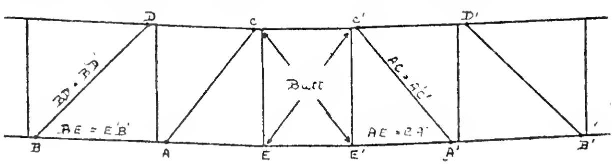

FIG. 6.

follows, and this method will at the same time give you the angle of incidence:

Throw a string over the top of both spars of the wings. Keep the string tight by attaching a weight or by attaching it to some heavy object. The strings should touch the wings at points just inside the top of the outer struts. The measurement taken from the blue print is then from the string to the top of the center section near the center section struts. This measurement should be taken near the struts and no attempt should be made to take the set measurement near the center of the center section. The wings on each side should be symmetrical, and this is insured by making the landing wires in corre-

sponding bays equal. The spars should be kept straight. Sometimes the diagonal measurements are taken from the bottom of one strut to the top of another, but this is wrong on account of possible inaccuracies due to faulty manufacture. The points between which the diagonal measurements are taken must be at fixed distances from the butt of the spars. Such distances being exactly the same on each side of the machine, thus:

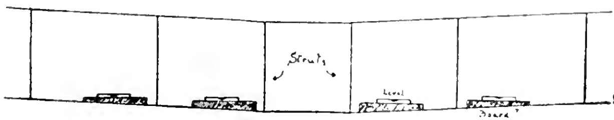

FIG. 7.

It would be better still to use the center line of the fuselage instead of the butt of the spars but for the fact that such a method is a troublesome one.

Another method of securing the dihedral angle and also the angle of incidence is by means of the dihedral board. The dihedral board is a light, handy thing to use but leads to many errors and should not be used unless necessary. The reasons are as follows: The dihedral

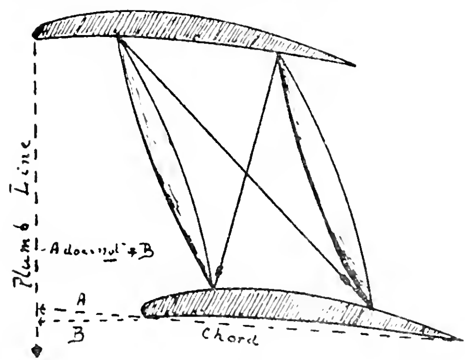

FIG. 8.

board is probably not true. If you must use it, then be very careful to test it for truth beforehand. Another reason against its use is that you have to use it on the spars between the struts, and that is just where the spars will have a little permanent set up or down which will, of course, throw out the accuracy of the adjustment. Then, again, there may be inequalities of surface on the spar due to faulty manufacture. The method of using it is as follows:

If the dihedral board is used, then the bays must be carefully measured diagonally as explained above. Whichever method is used, be sure that after the job is done the spars are perfectly straight.

Stagger.—The stagger is the distance the top plane is in advance of the bottom plane when the machine is in the flying position. The set measurement is obtained as follows:

The plumb lines must be dropped over the leading edges wherever struts occur and also near the fuselage. The set measurement is taken from the front of the lower leading edge to the plumb line. Remember that it makes a difference whether you measure along a horizontal line (which can be found by using a straightedge and spirit level) or along a projection of the chord. The correct line along which to measure is laid down in your rigging diagram. If you

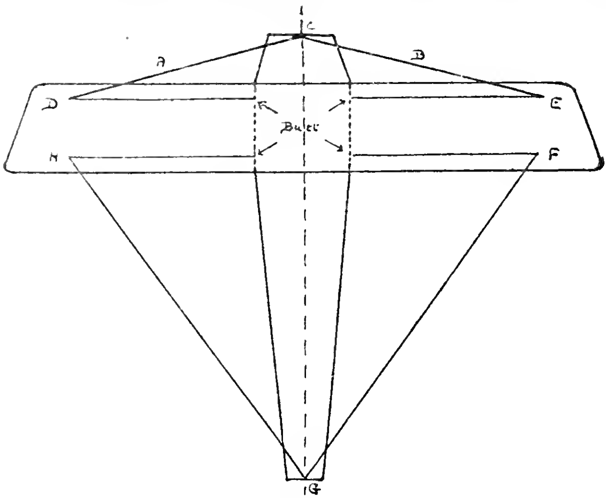

FIG. 9

make a mistake and measure along the wrong line, this may make a difference of a quarter of an inch or more to the stagger, with the certain result that the airplane will be nose or tail heavy. If the stagger was put correctly on the center section in the first instance, it should be correct when the main planes are affixed.

Now adjust the drift and antidrift wires.

When the adjustment of the angles of incidence, dihedral angle, and stagger have been secured, the incidence wires and the flying wires should be tightened. When this has been done, run over all your measurements again, as these last adjustments may possibly have thrown out your original ones.

Over-all adjustments.—The following over-all measurements should now be taken:

The straight lines "A" and "B" must be equal. The point "C" is the center of the propeller thrust. The points "D" and

"E" are marked on the main spar and must in each case be the same distance from the butt of the spar. Do not attempt to make "D" and "E" merely the sockets on the outer struts, as they may not have been placed quite accurately by the manufacturers. The lines "A" and "B" must be taken from both top and bottom spars—true measurements on each side of the airplane. Now measure the distance between "F" and "G" and "H" and "G." These two measurements must be equal. "G" is the center of the fuselage or rudder post. "F" and "H" are points marked on the top and bottom rear spars, the same distance from the butt, as was done before. If these over-all measurements are not correct, then it is probably due to some of your drift or antidrift wires being too tight or too slack. It may possibly be due to the fuselage being out of true, but, of course, you should have made quite sure that the fuselage was true before rigging the rest of the machine. Again, it may be due to the internal bracing wires not being accurately adjusted; but, again, that should have been done before covering the plane with fabric.

The tail.—The tail may be either an adjustable tail or a fixed one. The angle of incidence or the mean angle is given in the rigging diagram. If the tail is adjustable, see that the control is in the center before attaching the tail plane. To true up, see that the spars are horizontal. If they are tapered spars, see that their center lines are horizontal. The spars should be straight and the corresponding bracing wires on either side should be equal and should bear equal strains. Verify the position of the tail plane by standing behind the machine and seeing that it is symmetrical with the center of the main planes. In some machines there is an adjustment for changing the ang e of incidence of the stabilizer. The greatest care should be taken when increasing the angle of incidence on the tail. Only a comparatively small increase in the incidence makes the machine dangerously unstable, as explained in theory of flight. If a machine is nose or tail heavy, after it has once been trued up properly, it is probably due to the fuselage becoming strained rather than a wrong angle on the tail, and the fuselage should be retrued before the tail is touched.

Control surfaces.—Before attaching the control surfaces, lash the control lever and the rudder bar in the central position. The pilot depends entirely on these control surfaces for managing the plane, so that the greatest care must be exercised in properly adjusting these surfaces. When the surfaces have been attached to the planes, never let them hang down without support, as this strains the hinges.

The ailerons should be rigged so that when the machine is in flight they are in a fair, true line with the surface in front and to which they are hinged. The ailerons are hinged to the main planes and

are then attached to the aileron balance cable or balance springs. This cable should be adjusted so that the rear edge of the aileron is 1 inch (may alter with type of machine) below the trailing edge of the plane. Connect the control cables to the ailerons. Remember that controlling surfaces must never be adjusted with a view to altering the stability of the machine. Nothing can be accomplished in that way. The only result will be that the control of the airplane will be spoiled. If the ailerons are adjusted too high, the machine feels "floppy." If the ailerons are adjusted too low, it makes the machine unstable and tiring to fly. In both cases the machine is inefficiently rigged.

The elevators, like the ailerons, should set fairly behind the tail plane when the machine is in flight. Because the controls can not be adjusted too tightly, the elevators also must hang down a little bit when the machine is at rest. They should be adjusted symmetrically on either side, and this should be checked by eye as well as by measurement.

The rudder is sometimes set at a small angle with regard to the center line of the machine in order to help the adjustment for torque of engine. This adjustment should be checked also by eye and measurement.

Control cables.—The adjustment of control cables is quite an art and upon it will depend, to a large degree, the quick and easy control of the airplane by the pilot. Having rigged the controlling surfaces, remove the lashing which has kept the levers in the central position. Then, sitting in the pilot seat, move the control levers smartly. Tension up the control cables so that when the levers are smartly moved there is no perceptible snatch or lag. Be careful not to tension up the cables more than is necessary to effect this. If you tighten the control cables too much, they will bind round the pulleys and the result is hard work for the pilot and it also throws dangerous stresses upon the controlling surfaces, which are sometimes of rather light construction. It will also cause the cables to fray round the pulleys quicker than would otherwise be the case. Now, having tensioned the cables sufficiently to take out the snatch or lag, place the levers in their neutral position and move them backwards or forwards not more than an eighth of an inch either side of the neutral position. If the adjustment is correct, you should be able to see the controlling surfaces move. If they do not move, the control cables are too slack.

Tail skid.—The tail skid is usually made of ash and is stream lined. Care should be taken that the tail-skid spring is at the proper tension. If it is too loose the machine may jar heavily on the rudder-post, and this will strain the whole fuselage. A safety cable should be fitted through the tail-skid spring to prevent the front end stick-

ing into the ground in case of a bad landing. If the skid is steerable it is controlled by cables working from the rudder bar, and these controls should have springs on them to prevent sudden jerks coming on the rudder bar and surface.

The landing gear.—The landing gear must be very carefully aligned as laid down in the rigging diagram.

1. Be very careful to see that the landing gear struts bed down well in their sockets. If this is not done, then after a few rough landings they will bed down farther and throw the landing gear out of alignment, with the result that the machine will not taxi straight.

2. When rigging the landing gear, the airplane must be blocked up in its flying position, and sufficiently high so that the wheels are off the ground. When in this position the axle must be horizontal.

3. Be very careful to see that shock absorbers are of equal tension and that the same length of elastic cord and the same number of turns are used in each absorber.

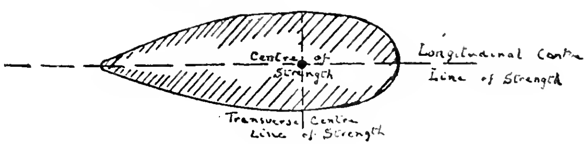

FIG. 10.

4. Errors in the fore-and-aft adjustment of the axle may make the machine unstable when landing; and the machine may either pitch onto the propeller or break the tail at the moment of landing if the adjustment is not correct.

Covering the fuselage.—When covering the fuselage, start from the front and top and work backward, so that there will be no hole near the engine to catch oil. Lace the fabric fairly tight so as to make the skin friction small. If there are any overlaps, make them so as not to catch the wind.

Allowance for torque of propeller.—This may be taken up on the wings or by the rudder or both. To adjust the wings it will be necessary to increase the angle at the tip of one plane and decrease it an equal amount on the other. That is, give the planes "wash out" or "wash in." If the propeller rotates right-handed in a tractor, it will be necessary to increase the angle on the left main plane. A tractor machine with a right-handed propeller will also require a little right rudder. In some machines it has been customary to take the allowance for torque on the ailerons, but this is a bad practice.

Spars and struts.—All spars and struts must be perfectly straight.

The above diagram shows a section through an interplane strut. If it is to be prevented from bending, then the stress of compression

must be equally disposed round the center of strength. If it is not straight, there will be more compression on one side of the center of strength than on the other side, in which case the strut will be forced to take a bending stress for which it was not designed. Even if it does not break it will in effect become shorter, and thus throw out of adjustment all the wires attached to the top and bottom of it, with the result that the flight efficiency of the airplane will be

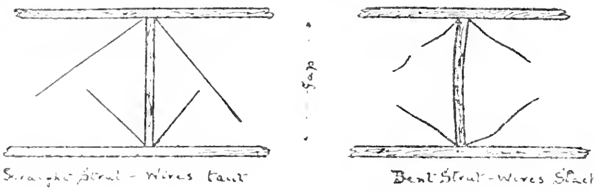

FIG. 11.

spoiled. Besides, an undue and dangerous stress is being thrown upon other wires.

1. Where spars are concerned, there is an exception known as *the arch*. For instance, in the case of the Maurice Farman, the spars of the center section plane, which have to take the weight of the nacelle, are arched upward. If this was not done, it is possible that rough landings might result in the weight of the nacelle, causing the spars

FIG. 12.

to bend down a little. This would produce a dangerous bending stress, but as long as the wood is arched, or at any rate kept from bending downward, it will remain in direct compression and no danger can result.

2. Struts and spars must be symmetrical; by that I mean that the cross-sectional dimension must be correct, as otherwise there will be bulging places on the outside, with the result that the stress will not be evenly disposed around the center of strength and the bending stress will be produced.

3. Struts, spars, etc., must be properly bedded into their sockets or fittings. To begin with, they must be a good pushing or gentle

tapping fit. They must never be driven with a heavy hammer. If the sockets do not fit, it is better for them to be too large than too small. Again, spars and struts must bed well down all over their cross-sectional area; otherwise the stress of compression will be taken on one part of the cross-sectional area, with the result that it will not be evenly disposed around the center of strength, and that will produce a bending stress. The bottom of struts or spars should be covered with some sort of paint, bedded into the socket or fitting and then withdrawn, to see if the paint has stuck all over the bottom of the fitting.

4. Do not trust to the angle of the socket being correct when the machine is rigged for the first time; and, as the planes are being adjusted, keep an eye on all sockets to insure that the edges do no damage the wood fibers.

5. The atmosphere is sometimes much damper at one time than another, and this causes the wood to expand and contract appreciably.

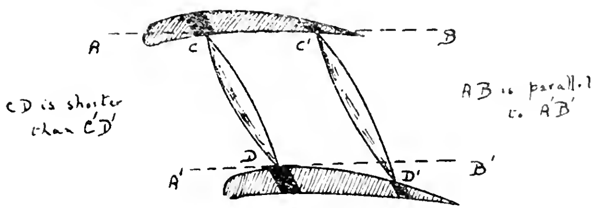

FIG. 13.

This would not matter but for the fact that it does not expand and contract uniformly but becomes unsymmetrical or distorted. This should be minimized by varnishing the wood well to keep out the moisture. This can be done with airplane dope, which is very good for the purpose.

6. Sometimes, for lightness, a fitting is bolted onto the end of a strut, and fabric is wound round the end to prevent the strut splitting.

The function of interplane struts.—These struts have to keep the planes apart and they must also keep them in their correct attitude. This is only so when the spars of the bottom plane are parallel to those of the top. The chord of the top plane must also be parallel with the chord of the bottom plane. If that is not so, then one plane will not have the same angle of incidence as the other. You may think that all you have to do is to cut all your struts of the same length, but that is not the case.

Sometimes, as illustrated in the diagram, the rear spar is not as thick as the main spar. It is then necessary to make up for the lack of thickness by making the rear struts correspondingly longer. If that is not done, the top and bottom chords will not be parallel and

the top and bottom planes will have different angles of incidence. Also, the sockets or fittings or even spars upon which they are placed sometimes vary in thickness and this must be offset by altering the length of struts. The proper way to proceed in order to make sure that everything is right is to measure the distance between the top and bottom spars on each side of each strut, and if that distance or "gap," as it is called, is not as specified in your rigging diagram, make it correct by changing the length of your strut. When measuring the gap between the top and bottom spars, always be careful to measure from the center of the spar, as it may be set at an angle and the rear of the spar may be considerably lower than its front.

Wires.—The following points must be carefully observed where wire is concerned:

1. Quality: It must not be too hard or too soft. An easy practical way of learning to know the quality of wire is as follows: Take three pieces of wire all of the same gauge, and each about a foot in length; one piece should be too soft, another piece should be too hard, and the third piece of the right quality. Fix them in a vise about an inch apart and in a vertical position, and with the light from a window shining upon them. Burnish them, if necessary, and you will see a bar of light reflected from each wire. Now bend the wires over as far as possible; where the soft wire is concerned, it will squash out at the bend and you will see this because the bend of light will have broadened out there. In the case of the wire which is too hard, the bend of light will be broadened out very little at the turn, but if you look carefully you will see some little cracks or roughnesses on the surface. In the case of the wire of the right quality, the bend of light may have broadened out a very little at the turn, but there will be no cracks or roughnesses in it at all. By making this experiment two or three times, you will soon learn to know good wire from bad and also learn to know strength of hand necessary to bend the right quality.

2. Wire must not be damaged; that is to say, it must be unkinked, rustless, and unscored.

3. As regards keeping wire in good condition, where the outside wires are concerned, they should be kept well greased or oiled, especially where bent over at the ends. This does not mean that large bits of grease must be left on the wires, simply that there should be a film of oil. In the case of internal bracing wires, which can not be reached for the purpose of regreasing them, you will prevent them from rusting by painting them with white-lead paint. You must be very careful to see that the wire is perfectly clean and dry before painting with white-lead paint. A greasy finger mark is sufficient to stop the paint from sticking to the wire. In such a case, there will

be a little space between the paint and the wire. Air can enter there and cause the wire to rust under the paint. The paint should be of a light color so as to show any signs of rust.

4. Wires and cables may be stream lined by binding onto them a V-shaped faring made of spruce. The wire and faring can be then painted to decrease the resistance. For single wires, this is not much of a gain, as a semicircle or triangle is a bad form of stream line. For the duplicated flying wires it is an advantage, as it prevents them vibrating separately and thus helps to decrease the head resistance. In any case, wires where they cross should be joined together by threading them through a little stream-line fiber washer.

Tension of wires.—The tension to which you adjust the wires is of the greatest importance. All the wires on the airplane should be of the same tension, otherwise the airplane will quickly become distorted and fly badly. As a rule, the wires are tensioned too much. The tension should be sufficient to keep the framework rigid. Anything more than that spoils the factor of safety, throws various parts of the framework into undue compression, pulls the fittings into the wood, and will, in the end, distort the whole framework of the airplane. Only experience will tell you what tension to employ and assist you in making all the wires the same tension. Learn the construction of various types of airplanes, the work the various parts do, and cultivate a touch for tensioning wires by constantly handling them. While at rest the landing wires will bear more strain than the flying wires on account of the weight of the plane. The opposite happens when the machine is in the air. If the flying wires are trued up slackly, the whole rigging of the airplane alters directly the machine gets into the air. In some cases you will find wires having no opposing wires pulling in the opposite direction. In such cases, be extremely careful not to tighten such wires beyond taking up the slack. If care is not taken, the incidence of the plane will be changed, resulting in change of both lift and drift at that part of the plane. Such a condition will cause the machine to lose its directional stability and also to fly one wing down. I can not impress this matter of tension upon you too strongly. It is of the utmost importance. When you have learned this and also learned to be accurate in getting the various adjustments you are on the way to becoming a good rigger.

Wire loops.—Wire is often bent over at the end in the form of a loop. These loops, even when made perfectly, have a tendency to elongate, thus spoiling the adjustment of the wire. Great care should be taken to minimize this as much as possible. The rules to be observed are as follows:

1. The size of the loop should be as small as possible within reason. By that I mean that it should not be so small as to create the possibility of the wire breaking.

2. The shape of the loop must be symmetrical.

3. The loop should have good shoulders in order to prevent the ferrule from slipping up. At the same time the shoulders should have no angular points.

5. The ferrule should fit the cable; if it is too large the loop will slip anyhow.

6. When the loop is finished it should be undamaged and should not be, as is often the case, badly scored.

7. Wires up to 12 gauge should be bent easily by hand with the aid of a round-nose plier. The bending should be done firmly and quickly. This is quite a knack with the larger sizes of wire.

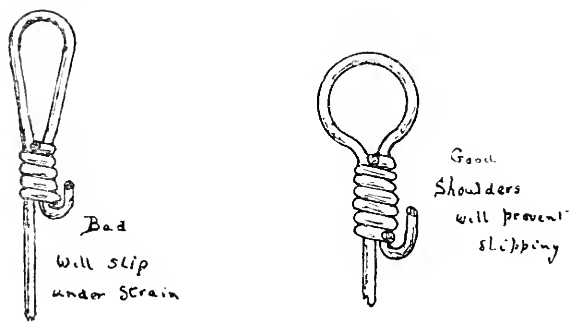

FIG. 14.

Stranded wire cables.—There are two kinds of cable used in rigging airplanes, one of which is much harder than the other. The loops on the first are usually made by serving the cable with wire and then soldering. Loops on the latter, the softer wire, may be made by splicing. When serving the cable with wire the winding must be even, with a nice stream-line effect at the end of the winding. When solder is used care must be taken that the flux does not go beyond soldered portion of cable. Only *nonacid flux* should be used in soldering. The length of the served portion should be at least fifteen times the diameter of the cable as shown in diagram.

If the cable is spliced, every strand must take its proper share of the strain. Sharp turns should be avoided. When hammering the splice, a sharp or too hard an instrument should not be used, as this is liable to injure the strand. No splice should be served with twine until it has been inspected and passed by whoever is in charge of the shop. Only the very end of the splice should be served, as this

is only intended to prevent the short ends of wire from coming away from the strand. Stranded cable when overstrained nearly always breaks just above the splice. Thimbles of soft metal should always be used with stranded cable. Should a strand become broken, then the cable must be replaced by another. Control cables have a way of wearing out and fraying whenever they pass over the pulley. Every time an airplane comes down from a flight the rigger should carefully examine the cables wherever they pass round pulleys, and if he finds a strand broken he should report the fact at once. The aileron balance wire on top of the top plane is often forgotten, since it is necessary to fetch a high pair of steps in order to examine it. Do not neglect this. Both wires and cables are liable to be damaged where they cross; to prevent this, a little block of fiber, stream-lined, is threaded on to the cables so as to prevent them touching. The wires of the interior of the machine may be wrapped with adhesive tape but as this collects moisture it is not a good thing to use this tape on those cables exposed to the air.

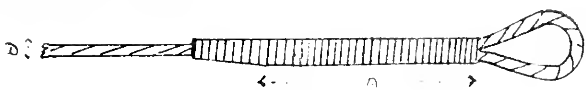

FIG. 15.

All the cables should be stretched before fitting and should be well greased where they run through pulleys or fair-leads. Fair-leads should be made of rawhide, rather than of metal, as rawhide gives less wear. When a cable is being inspected to see if it is frayed, all the old oil must be wiped off and the fingers should be gently run over the suspected place. Any broken strands will be easily felt. Sometimes the inner strands are broken, and this may be found out by very gently bending the cables backward and forward.

Cables may be cut by heating quickly in a blow torch flame. This makes the wire soft and also keeps the ends from fraying. Care must be taken not to let the heat travel far down the cable, and this can be done by holding cable in metal to conduct away the heat.

Stream-line wires.—Stream-line wires are made by rolling steel rods. They are screw threaded at either end with a left and right handed thread. These rods are cut to length for each machine so that if one breaks a special rod has to be obtained in order to replace it. The ends of these rods fit into special Y-shaped fittings, which are also left and right hand threaded to fit onto the ends of the rod. The rods also carry a locking nut at each end so that when the

required adjustment is made, the wires can be fixed there. The end fittings are pinned to the wiring plates on the planes by means of special steel pins. There is a small hole, about halfway down each fitting, and to be safe the end of the wire must pass this hole. There is another kind of fitting in which the wire is screwed through a little metal rod. This latter is a better method, as it allows the wires to vibrate without putting any side strain on them. The wires must lie in the flow of air in the same manner as do the struts. By using stream-line wires the lift of the machine is increased appreciably and the speed a little. When stream-line wires are overstrained they tend to draw out just above the screw-threaded portion, and this can easily be felt by running the fingers down the edge of the wire and can be seen. Stream-line wires should be kept bright and slightly oiled.

Tension rods.—These are rods used in the construction of many fuselages, and the same rules apply to them as to stream-line wires, except that they are round and can be locked in any position.

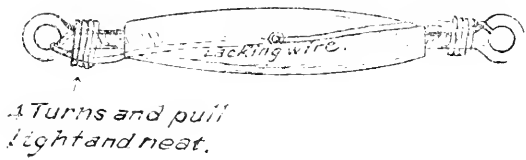

FIG. 16.

Turnbuckles.—A turnbuckle is composed of a central barrel, into each end of which is screwed an eyebolt. The bolts at either end are screw threaded left and right handed. Wires are taken from the ends of the eyebolts, and so by turning the barrel the wires can be adjusted to their proper tension. Eyebolts must be a good fit in the barrel; that is to say, not slack and not very tight. There is a rule that the eyebolts must be screwed into the barrel for a distance of not less than thrice their diameter, but it is better to screw them in a good deal more than that. If the eyebolt is screw threaded for only a short distance, the bolts should be screwed into the barrel till the last thread is flush with the end of the barrel unless otherwise stated. The turnbuckle should not be tightened so that the ends of the eyebolts meet in the middle. If this happens, new cables must be fitted. Turnbuckles are chosen of a size corresponding to that of the cable used with them. The barrel of the turnbuckle looks solid but is really hollowed out and is much more frail than it appears. For that reason it must not be turned by seizing it with pliers, as that

may distort it or spoil the bore. The proper method is to pass a piece of wire through the hole in the center and to use that as a lever. The eyebolts may be prevented from turning by holding them on the ends of another piece of wire. When the correct adjustment is obtained, the turnbuckle must be locked to prevent it from unscrewing. It is quite possible to lock the turnbuckle in such a way that it allows it to unscrew a quarter or half turn, and that will throw the wires out of the very fine adjustment necessary. The proper way is to use the locking wires in such a way as to oppose the tendency of the turnbuckle to unscrew, as is shown in the diagram.

The wire used for locking a turnbuckle is hard copper wire or soft iron wire. Turnbuckles on internal wires must be well greased and served round with adhesive tape after they have been locked. On no account may the barrel of a turnbuckle be sawed off short.

In case of a forced landing, it may be necessary to mend the machine from materials at one's disposal locally, and it is useful to know a little about the materials used in the construction of a machine.

METAL.

1. There should be no signs of rust or flaws.

2. Only bright bolts and nuts should be employed. In airplane construction, bolts, nuts, and pins are made of special steel and those obtained locally should be looked on with suspicion as they are almost certain to be too weak.

3. Piano wire should not have been previously bent and must be free from kinks.

4. Stranded wire or cable should be regularly twisted and not frayed at any point.

5. Tubing should be perfectly straight and should not show signs of having been previously bent and subsequently straightened. Tubing is usually welded into its sockets, but if there is much vibration tubes should be attached to the sockets by being pinned and then soft soldered. In case an axle becomes bent, it can be mended temporarily by being straightened and by having a wood (ash) core put in. This should bring the machine home.

6. Threads of bolts, nuts, and screws should be clean and not worn or burred. Make certain that these are screw threaded on the same system and that they have the same number of turns to the inch.

7. Strut sockets and other metal fittings should not be bent out of their original shape. Such fittings should not be used if they show signs of having been bent and subsequently straightened.

In the case of aluminum sockets, care must be taken that there are no cracks, especially where the sockets have previously been subjected to severe strains. Eyeplates and eyebolts should show no signs of wear or fracture. Wiring plates can be replaced temporarily by those made from mild steel. Allow plenty of metal so as to insure the plates being strong enough. This again must be only a temporary measure. The properties of iron are described under "Engine material."

8. All metal fittings should bear the inspection mark before being used on an airplane. Any fitting which has been subjected to a strain should be inspected by a qualified officer or returned to the salvage section, and this latter applies to all airplane material.

9. No bolt, pin, or turnbuckle should be used if it has been bent.

WOOD.

The correct wood for the various parts of an airplane must be used. The wood used must have a good clear grain, with no cross grain, knots, or shakes. Such blemishes mean that the wood is in some places weaker than in other places, and, if it has a tendency to bend, then it will go at those weak points. All wood must be properly seasoned. Struts, spars, etc., must be straight and undamaged. When a bending stress comes on one of these members the outside fibers of the wood are doing by far the most work. If these get bruised or scored, then the strut or spar, suffers in strength much more than one might think at first sight, and, if it ever gets a tendency to bend, it is likely to go at that point. The two woods most generally used in airplane construction are ash and spruce. Spruce is the strongest wood for weight that grows. Ash is a very strong but heavy wood, but it is very good at resisting sudden shocks and will bend considerably before breaking. As a general rule, spruce is used for the main spars, struts, compression ribs, and the flanges of form ribs. Ash is used in the longerons, in the undercarriage struts, in skids, and in the three-ply webs of form ribs. It is also used for engine bearers, if metal is not employed. No spar, strut, etc. should be bored in any place where a hole was not designed. If anything is to be fitted to a spar, it should be clipped round it with a suitable clip. Holes in wood should be of a size that the bolts can be pushed in, or at any rate not more than gently tapped in. Bolts must not be hammered into wood, as doing this splits the wood. On the other hand, a bolt must not be slack in a hole, as it works sideways and may thus split the spar, not to speak of throwing out of adjustment the wires leading from the lug or

socket under the bolthead. As has been before stated, all wood should be well varnished so as to prevent damp creeping in and causing expansion or contraction of the fibers. In case of emergency, where the proper wood is not obtainable, make certain that the wood used is sufficiently strong to carry the strain.

Nature of wood under stress.—Wood for its weight takes the stress of compression best of all. For instance, a walking stick of about half a pound weight will, if kept perfectly straight, probably stand up to a compression stress of a ton or more before crushing, whereas if the same stick is put under a bending load it will probably collapse to a stress of not more than 50 pounds. That is a very great difference, and since weight is of the greatest importance in an airplane the wood must as far as possible be kept in a state of direct compression.

Splicing wood.—In the case of a fracture occurring in a solid spar or one of the box type that is wide enough (2 inches) it is often possible to make a good repair by scarfing on a new length. The scarf must be long compared to the depth of the spar and the two pieces of wood forming it must be a good fit onto each other. After fitting the two halves of the scarf together they must be well glued and then clamped together till the glue is set. The joint is then planed up and examined to see that it is a close one and does not have a thick layer of glue between the two thicknesses of wood. The two halves of the scarf are then bolted together as an additional precaution, large washers being employed under the bolthead and nut so as to prevent them from cutting into the wood and crushing it when tightening the nut. A waxed whipcord lashing is then served round the joint, each turn of the cord being securely knotted to prevent it coming adrift. The cord may be glued finally as a further precaution.

STRESSES AND STRAINS.

In order to rig a machine intelligently it is necessary to have a correct idea of the work every wire and every part of the airplane is

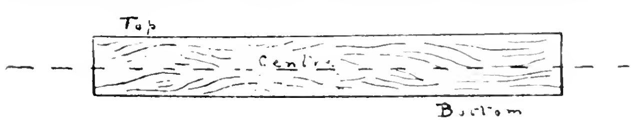

FIG. 17.

doing. The work the part is doing is known as stress. If owing to undue stress the material becomes distorted then such distortion is known as strain.

Compression.—The simple stress of compression produces a crushing strain. As an example the interplane and fusilage struts.

Tension.—The simple stress of tension results in the strain of elongation. As an example all the wires.

Bending.—The compound stress of bending is composed of both tension and compression. Now we will suppose we are going to bend a piece of wood. Before being bent it will have the following appearance:

You see that the top line, the bottom line, and the center line are all of the same length. Now we will bend it right round in a circle, thus

The center line is still the same length as it was before being bent, but you will note that the top line being on the outside of the circle must now be longer than the center line. That can only be due to the strain of elongation. That is produced by the stress of tension. So you see that the wood between the center line and the line on the outside of the circle is in tension. The greatest tension is on the outside of the circle because there the elongation is greatest.

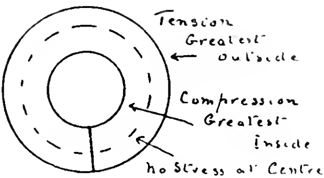

FIG. 18.

You will notice that the line on the inside of the circle which before being bent was the same length as the center line must now be shorter because it is nearest to the center of the circle. That can only be due to the strain of crushing. That can only be produced by a state of compression. So you see that the wood between the center line and the inside line is in compression and the greatest compression is nearest to the inside of the circle because there the crushing effect, i. e., the strain, is greatest.

By this you will see that the wood near the center line is doing the least work. That is why it is possible to hollow out the center of spars and struts without unduly weakening them. In this way 25 to 33 per cent of the weight of wood in an airplane is saved.

Shear.—Shear stress is such that when the material breaks under it one part slides over the other. As an example the locking pins. Some of the bolts are in a state of shear stress also because in some cases there are lugs underneath the boltheads from which wires are taken. Owing to the tension of the wire the lug is exerting a sideways pull on the bolt and trying to break it in such a way as to make one part of it slide over the other.

Torsion.—The stress of torsion. This is a twisting stress composed of compression, tension, and shear stress. As an example the propeller shaft and crank shaft of an engine.

Washers.—Under the bolthead and also under the nut a washer must be placed. This should be a very large washer compared with any other form of engineering. This is to disperse the stress over a large area of wood; otherwise the washer may be pulled into the wood and weaken it, besides possibly throwing out of adjustment the wires attached to the bolt or fitting.

Locking.—As regards locking the bolts if split pins are used be sure to see that they are used in such a way that the nut can not possibly unscrew. If a castellated nut is used the pin should fit the hole in the bolt so that it will not be sheared by the edge of the nut. If a plain nut is used washers should be put under the nut so that it reaches exactly to the bottom of the hole in the bolt or the nut may be filed a little bit to allow it to go down past the hole. If a bolt is locked by burring over the end a heavy hammer must not be used in order to try and spread the whole head of the bolt. That might damage the woodwork inside the plane. Use a small, light hammer and gently tap around the edge of the bolt until it is burred over. All bolts and nuts should be locked in a positive manner. A split-ring washer does not lock a nut in this manner and should not be used without some other form of locking as a rule.

HANDLING OF AIRPLANES.

An extraordinary amount of damage is done by the mishandling of airplanes and in blocking them up from the ground in the wrong way. The golden rule to observe is "*Produce no bending stresses.*"

1. Remember that nearly all the wood of an airplane is designed to take stress of direct compression and it can not be safely bent. In blocking an airplane up from the ground the packing must be used in such a way as to come underneath the interplane struts and the fuselage struts. Soft packing should always be placed on the points upon which the airplane rests.

2. When pulling the machine along the ground, always, if possible, pull from the landing gear. If it is necessary to pull from elsewhere do so by grasping the interplane struts as low down as possible.

3. Never lift or put any strain on the leading and trailing edges of the planes and do not cover them with oily finger marks.

4. As regards handling parts of airplanes, never lay anything covered with fabric on a concrete floor as any slight movement will cause the fabric to scrape over the concrete with resultant damage.

5. Struts, spars, etc., should never be left about the floor, as in such a position they are likely to become damaged; and I have already explained how necessary it is to protect the outside fibers of the wood. Remember also that wood easily becomes distorted. This particularly applies to the interplane struts. The best method

of storing struts is to stand them up in as near a vertical position as possible.

6. When lifting an airplane as might have to be done when the landing gear is broken, it is convenient to lift the machine by putting one's shoulders under the main spar and under an interplane strut and lifting with one's back. When lifting the tail of a machine lift under one of the fuselage struts just in front of the tail plane. The best place is usually marked by an arrow.

7. Planes kept temporarily in the hangars should be kept slung in broad bands of webbing. A 2-inch batten should be threaded through the loops of webbing and the leading edge of the plane should be placed on this to prevent its being distorted.

8. Planes packed in the wing trailer should be supported under the compression ribs on pieces of felt. These pieces of felt are made to fit the camber of the plane on both top and bottom.

9. When a machine is standing in the sheds the weight of the machine should be taken off the shock absorbers. This is conveniently done by placing the landing gear on blocks of wood. The tail should be supported on a trestle in a proximately the flying position. This takes the weight off he tail and prevents the fuselage being in a continual state of stress.

KEEPING AN AIRPLANE IN GOOD ONDITION.

Cleanliness.—The fabric must be kept clean and free from oil, otherwise it will rot. To take out dirt or oily patches try acetone. If that will not do try gasoline. Both acetone and gasoline should be used with caution as they both have an effect on the dope and varnish. The best way to keep the planes clean is to use soap and warm water, but in that case be sure to use a soap having no alkali in it as otherwise it will badly affect the fabric. Use water sparingly or it may get inside the planes where it tends to rust the wires and swell the wooden framework. The wheels of the landing gear have a way of throwing up a great deal of mud on the lower planes. This should be taken off at once. Do not allow it to dry and do not try to scrape it off when dry. If it is dry then it must be moistened first as otherwise the fabric will be spoiled. A good cleaning solution is a pail of warm water, with soft carriage soap and some Gold Dust.

Controlling wires.—After every flight pass your hand over the wires and carefully examine them near the pulleys. If only one strand is broken the wire must be changed. Not only does a broken strand weaken the cable but it may become jammed and prevent the pilot using one of his controls. Do not forget the aileron balance wire

on the top plane. Once a day try the tension of the control wires by smartly moving the control levers about as explained before.

Wires.—See that all wires are kept well greased or oiled and that they are in the same tension. When examining your wires be sure to have the machine on level ground, as otherwise it may get twisted, throwing some wires into undue tension and slackening others. The best way, if you have time, is to pack the machine up into its flying position. If you see a slack wire do not jump to the conclusion that it must be tensioned. Perhaps its opposite wire is too tight, in which case slacken it and possibly you will find that will tighten the slack wire. Carefully examine all wires and their connections near the propeller and be sure that they are snaked around with safety wire so that the latter may keep them out of the way of the propeller if they come adrift.

Distortion.—Carefully examine all surfaces including the controlling surfaces to see whether any distortion has occurred. If distortion can be corrected by the adjustment of a wire, well and good, but if not then report the matter.

Adjustment.—Verify the angle of incidence, the dihedral angle, the stagger, and the overall measurements as often as possible. Alterations in all these cause inefficiency, but as one measurement usually depends on another, no alteration should be made without orders from the pilot.

Landing gear.—Constantly examine the alignment and fittings of the landing gear, the condition of tires, shock absorbers, and the tail skid.

Control surfaces.—As often as possible verify the rigging position of the ailerons and elevators. This should be done by the pilot when the machine is in flight as well as when the machine is on the ground.

Locking arrangements.—Constantly inspect the locking arrangements of all turnbuckles, bolts, etc.

Outside position.—The airplane when outside its hangar must always stand facing the wind. If this is not so then the wind may catch the controlling surfaces and move them sharply enough to damage them. If the airplane must be moved during windy weather then the control levers should be lashed fast. It is a good thing always to do this when getting out of the machine, but the lashing should be fixed so that the pilot can not sit down and therefore can not go up into the air with his controls lashed.

Inspecting.—Learn to become an expert. Whenever you have the opportunity practice sighting one strut against another to see that they are parallel. Standing in front of the machine, which in such case should be on level ground, sight the center section plane against the tail plane and see that the latter is in line. Sight the leading

edge against the main spars, the rear spars, and trailing edges, taking into consideration wash in and wash out. You will be able to see the shadow of the spars through the fabric. By practicing this sort of thing you will after a time become quite an expert and will be able to diagnose by eye false efficiency, stability, and control.

Dismantling a machine.—If for any reason the machine has to be dismantled, the engine should be taken out first of all and then the wheels should be taken off; the tanks should also be emptied. This makes the machine light to handle and will save it from damage if it falls off the trestles, which are often very inefficient in the field. If the machine will have to be rerigged it saves a lot of time if every cable and strut is labeled and if all turnbuckles are kept on their proper cable. Pins should be put back in their proper places and tied in. The machine should be kept dismantled as short a time as possible. The longer a machine is kept so the more the parts become lost and damaged.

Packing machine in a truck.—Most two-seater machines can be packed in a 3-ton truck. After the tanks have been emptied the fuselage can be placed in the center of the truck and supported on suitable packing so as to prevent the sockets of the landing gear from being damaged. The wings can be placed on their edges on either side of the fuselage and it is convenient to prevent them from rubbing by supporting them on grass or straw and putting straw ropes between the planes themselves and the truck. The control surfaces can be tied to the top of the truck and they should be slung. If they are tied with string passed through the hinges the string will fray on account of the vibration of the truck.

Piping and cable.—Piping of all kinds must be arranged with a proper regard to the amount of vibration to which it will be subjected. Long unsupported lengths should be avoided. Gasoline and oil pipes usually break just below their attachments to the tank, etc. Vibration is more evenly distributed by fitting pipes with a curl just below the point of support. In metal piping it is often advisable to fit a joint of specially prepared rubber tubing close to the unions to prevent fracture. Although special rubber tubing is prepared to resist the action of gasoline and oil it will nevertheless gradually deteriorate and will require examination and renewal at short intervals. Chokes in pipes are frequently caused by deterioration of the lining of the tubing. The lining is often damaged by the edge of the tube which is too sharp.

High-tension cables should be protected at the points where they are supported to prevent the covers fraying. This may be done by binding them at these points with adhesive tape.

III. SAIL MAKING.

TOOLS AND MATERIALS USED IN SAIL MAKING.

1. Tools:
   - Scissors.
   - Hammer.
   - Ice pick.
   - Stringing needles.
   - Sewing needles.
   - Eyelet, punch, and dies.
   - Dope and varnish brushes.
   - Steel tape (50 feet).
   - 16K.33 sewing machine.
2. Materials:
   - Fabric.
   - Dope.
   - Varnish (light spar).
   - Varnish solvent (V114 thinners).
   - Acetone.
   - Thread, 30, 40, and 50.
   - Hemp string.
   - Copper tacks, $\frac{1}{4}$-inch.
   - Brass brads, $\frac{1}{2}$-inch.
   - Eyelets, bootblack.
   - Protective coloring (colored dope).

Fabric.—The fabrics used in sail making are the best Irish linen and cotton. Its weight is 4 ounces per square yard and this is increased to 6 ounces after it has been doped and varnished. Before being issued for use all fabric is subjected to the light test. The method of this test is to pass the fabric before a powerful electric light which shows very plainly all the flaws in the weaving. These flaws are marked with a blue pencil and when covering a plane all such marks are carefully covered with a patch. The threads which run across the fabric from selvage to selvage are called the weft and warp is the lengthways of the material. Doped fabric is stronger than undoped by about 4 per cent.

Dope.—This is a solution of cellulose which makes fabric air, gasoline, and water tight, reducing skin friction and strengthening the fabric. Also used as a method of sticking on patches. It can also be used on wood to make it waterproof. No nitrate base cellulose should be used, as it is highly inflammable.

Varnish.—The varnish used on a plane is special light airplane varnish. Certain varnishes must be used with certain dopes and

care should be taken that the proper varnish is used. Varnish increases the efficiency of dope, i. e., reduces the skin friction and the ill effects of differences of temperature, wet, etc.

Solvent.—The solvent is used to remove the varnish from a plane without unjuring the doped surface of the fabric. It can be used also for thinning out the varnish.

Acetone.—Can be used for thinning dope. It should be used with caution for cleaning the oil and dirt off the plane. Acetone alone should not be used on fabric, as it tends to make the fibers brittle.

Protective coloring.—When varnish is used on the top plane a colored pigment should be mixed with it. This mixture is called the protective coloring. Its use is to prevent the sun's rays rotting the fabric through decomposition of the dope. The coloring should not be applied to a varnished plane without first removing all varnish with a suitable solvent.

Covering.—Care should be taken before commencing to cover a surface, and the same applies to patching, that the supporting trestles are placed under compression ribs or main spars. Take note that all turnbuckles are locked and greased and then bound with strips of fabric or adhesive tape. All edges of ribs and main spars are then covered with strips of fabrics to prevent the cover rubbing on the wood. Measure width of plane from leading to trailing edge, double result and add 4 inches. This gives the measure or length each section of the cover should be cut. The fabric varies in width from 36 to 38 inches, so by measuring length of plane the number of sections or pieces of fabric required for cover can be found. These sections are then machined together by means of a seam known as the "balloon seam." This seam is made by turning the selvage of the fabric in a half inch and locking the two sections together. It is then machined on either side, thus

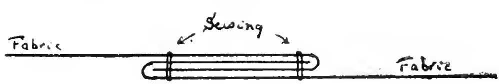

FIG. 19.

This seam has the same finish on each side. When all sections required are seamed together, fold the cover in two lengthways with the right side inside, thus finding the center. Crease the double edge with the fingers and lay the cover on the top side of the leading edge, keeping the creased edge of the cover on the leading edge. Tack at every rib. Eyelet holes are placed between each rib on the underside of plane at the trailing edge. This is done before oversewing round edge. These holes are for the escape of moisture which collects in all planes. Strain cover over to trailing edge and again

tack on each rib. Turn plane over and strain and tack fabric as on top. The fabric is then turned in on top and under sides at trailing edge and drawn together by means of a stitch known as the "oversewing stitch." The plane is then ready for stringing. An upholsterer's needle and hemp string is used and a stitch is placed every 3 inches across each rib. Place the needle through the plane on right of rib and bring down on left, keeping the needle close to the rib. Knot string on top.

Doping plane.—When the sewing has been finished the plane is given a coat of dope and this coat must be rubbed well in. When quite dry a 2-inch strip of fabric is placed over each rib and doped on. These strips are frayed out at sides half an inch. This is to make them adhere to the cover better. All edges are then bound with these strips. Another coat of dope is then rubbed in and then three more coats are evenly laid on. Each coat must be thoroughly dry before the next is applied and before applying each coat the plane should be rubbed down well with a piece of fabric. This is to remove all roughness and imparts a good polish to the plane. On no account use anything rough in the nature of sandpaper and do not apply too much pressure so as to make the fabric slacken off. Two coats of varnish evenly applied completes the plane. Doping and varnishing should be done on a dry day and in a hot room, temperature about 70°. If the room is too cold the varnish will dry with all the brush marks showing, but if the room is kept warm the varnish dries much slower and the brush marks have time to even out. Dope and varnish should be applied with a flat, 4 inch camel's-hair brush. If the room is damp or if the fabric is damp the dope dries in white patches instead of without color, as it ought to do. In some planes the fabric is adjusted on the bias; that is, the seams run diagonally across the plane instead of straight. This is supposed to be stronger and to prevent the fabric tearing in case it were damaged.

Redoping.—It is sometimes necessary to redope a plane or part of a plane. First of all, take off all the varnish with a suitable solvent. This is quite easily done and does not take long. Rub into the old dope fresh dope which has been thinned with acetone. This should be rubbed well in, so as to soften the old dope. Do not attempt to remove the old dope with acetone, because the acetone will probably dry out before the dope is properly softened, and acetone tends to make the fibers of the linen brittle. After the old dope has been softened by two coats of the thin dope two coats of ordinary dope should be applied and then two coats of varnish, as is done when doping the plane for the first time.

PATCHING.

If a plane is damaged in any way care should be taken to insure that none of the internal parts are damaged. It is sometimes necessary to make a comparatively large cut in a plane to insure this, although the original damage is slight. If a cut has to be made it should be made in a fore and aft direction. In repairing or patching a wing, first examine the tear and judge for yourself whether it should be sewn up or whether the damaged portion should be cut out, taking into account the condition of the fabric, the edges of the tear, and the part of the wing affected. If the damage be a clean cut running straight with the thread of the fabric the edges are drawn together with the herringbone stitch. The varnish is now carefully removed with a suitable solvent and the hole is covered with a patch square or rectangular, three-quarters of an inch larger than the tear. The edges of the patch are frayed out to make it stick better and the patch is stuck on with dope. Varnish on a plane prevents the dope sticking. A second patch is then doped over the first. This also should be frayed, the fraying being a quarter of an inch deep. Fraying allows the dope to get a firm grip of the edges of the fabric and makes it a better stream line; a small gain, but in the aggregate worth considering. The threads of the fraying must run all parallel to each other and must be flat with the first coat of dope. All patches should have three coats of dope and two of varnish, these being applied as described above. For sewing in a patch cut the damaged portion out in the form of a rectangle and slit the corners the length of an inch. Turn in the fabric as this gives a firm edge to which to attach the patch. Cut the patch the size of this opening and allow half an inch for turning in the edges. Make it fit the hole tightly and then sew it in with the herringbone stitch. The sewing must be perfectly regular, taking care that the stitches are all the same length and distance apart, as the strength of the patch depends on the regularity of your sewing. The patches are put on tight to pull with and match the cover of the wings, which is well strained on in the first place. The corners are often sewn very badly. When you get within a good length stitch of the corner the outside stitches must wheel round regularly, while those on the inside are much closer together, or so to say, marking time. Remember that the corner of a patch is always the weakest part. Nothing is gained by making the patch circular, because the edges must be turned in, and this in itself forms a corner. Dope this patch, put on a second three-quarters of an inch outside all stitching and then another three-quarters of an inch larger than this. Fray patches and dope on as described above. If you have a small patch to go on with a few

stitches underneath it may be put on with varnish instead of dope, but this does not apply to patches which have to be sewn in.

Storing fabric.—It is essential that fabric should be kept quite dry and clean, and it should therefore be stored in a dry place. If moisture is present when the fabric is being doped the dope will not penetrate properly and turns white. Planes when covered should be left in the doping room some time before the dope is applied so as to attain the temperature of the room.

DOPING.

Doping room. In order to insure good results in doping it is of vital importance that a special doping room be provided and great attention paid to the maintenance of a uniform temperature. Vapors from dope are heavier than air, so that outlets should be provided near the floor to extract the bad air from the room. Fresh air outlets should be provided high up in the wall opposite. Incoming air should pass over hot pipes so that the room may be maintained at a uniform temperature of 65° to 70°. At the front the nearest approach to this will be a tent or hangar heated tolerably by a brazier so that doping should be done on a sunny day when the sun has had time to dry up the atmosphere.

Storing of dope.—Dope is affected by the ultra-violet rays of the sun, so that it should be kept in light-tight vessels. Dope should not be stored for more than three months and should be used as supplied. Special solvents are used for loosening stuck stoppers and for washing brushes. Brushes may be kept immersed in dope and the whole covered by an inverted jar stuck to the table with dope, thus making an air-tight joint. Dope should be stored in a room at a temperature of about 60°.

Method of applying dope.—The brush should be well dipped into the dope, but care must be taken that drops of dope are not allowed to fall on the fabric as the brush is being carried to the point of work. The dope must be applied to the fabric with a smooth, backward and forward motion and air bubbles must not be formed. The first coat must be rubbed well in, particular care being taken on the parts covering the woodwork in order to make the fabric adhere to the wood. The dope must penetrate well through the fabric in order to "rivet" the coating to the fabric and prevent it peeling. In cases of doping schemes where a thin first coat is provided it will not be necessary to rub this coat in, because this may cause drops to form on the inner surface of the fabric. After the final coat of dope has been applied the plane should be left as long as possible, preferably about 12 hours before the varnish is put on. In some dopes the last coat contains the pigment, so that only one coat is necessary and can

be put on at once. Only upper and vertical surfaces are covered with pigment. The lower surfaces are covered with transparent varnish.

Identification marks should be painted on immediately after the last coat of dope and are covered with the last coat of transparent varnish.

Defects.—White patches are due to moisture in the air or fabric or to the doping being done at too low a temperature. With dopes in which acetone substitutes are used white patches frequently occur in the first coat, but should disappear when a second is applied.

Blisters are due to doping being done at too high a temperature. Patches refusing to dry with formation of blisters is due to faulty dressing of the fabric, probably traces of soap.

Cracks appearing in circles may be spots of new mold in the fabric. Circular cracks also appear if two coats of copal varnish are applied. Sunlight on unprotected dope causes it to deteriorate and crack.

Yellow patches appearing some time after the doping are probably due to dressing left in the fabric.

Sagginess is due to moisture or sometimes to the doping being done at too low a temperature.

MARKINGS ON AN AIRPLANE.

All airplanes should be marked as follows:

One insignia should be placed on each end of the upper surface of the top planes and one on the under surface of the lower planes. The circumference of the circumscribed circle should just miss the wing flaps.

The insignia consists of a five pointed star colored white with a blue circumscribed field; the center of the star is a red circle; the diameter of the circumscribed circle will be equal to the chord of the wing on which the insignia is placed. The diameter of inner circle will not extend to the inner points of the star by an amount equal to one twenty-fourth of the diameter of the circumscribed circle.

The inner circle should be painted red and that portion of the star not covered by the inner circle will be painted white; the remainder of the circumscribed circle should be painted blue.

The rudder should be painted in blue, white, and red vertical strips, the blue strip being nearest the rudderpost.

The rudder should be marked with the machine's number in 3-inch letters on the top of the white band.

The sides of body of the airplane should be left free of all markings except such as shall be ordered to be carried in the field.

One point of the star in each insignia will point to the front.

IV. ENGINES, MATERIAL.

Steel.—Steel is a form of iron containing a certain percentage of carbon and in some cases alloyed with small quantities of other metals such as nickel, chromium, vanadium, or manganese. The amount of carbon present and the treatment to which the steel has been subjected determine its mechanical properties.

The metal iron in a chemically pure state is only found in a chemical laboratory, but a good commercial wrought iron is reasonably pure. Wrought iron contains a very low percentage of carbon (up to about 0.25 per cent). It is ductile (it can be stretched), comparatively soft and fibrous in structure. Steel contains about 0.25 to about 2 per cent of carbon, and cast iron is an iron containing from about 2 to 5 per cent of carbon. In most cases cast iron also contains a percentage of silicon.

Steel containing a low percentage of carbon is called mild steel and is similar to wrought iron in its mechanical properties. It is comparatively soft and ductile, but is not fibrous in structure. It is used for bolts and nuts, operating-rod brackets, engine bearers, etc., and in general engineering for steam boilers, bridge girders, and constructional work generally where a brittle metal such as cast iron is unsuitable.

As the percentage of carbon is increased the character of the steel alters. It becomes harder and more brittle, but the amount of hardness depends upon the treatment the steel has received. To get maximum hardness a steel containing a fairly high percentage of carbon (e. g., tool steel or silver steel) should be heated to a bright red heat and immediately quenched in cold water or oil. The effectiveness of this hardening process depends upon the rapid cooling of the metal. In special cases, where exceptional hardness is required, the steel may be quenched in ice-cold mercury, which, being a good conductor of heat, brings about a very rapid cooling of the metal. A high carbon steel so treated is called "glass hard." It is in fact hard enough to cut glass and may be used for this purpose. It is, however, brittle and unsuitable for most purposes. Ordinary files and hack-saw blades are hardened in this manner and the brittleness of these tools is well known to those who have used them.

Glass-hard steel is too brittle for ordinary purposes and is therefore softened or "let down" by a further heat treatment, which is generally described as tempering. In this process the steel is first carefully cleaned so as to prevent a bright surface and heat is gradually applied. Shortly after the application of heat a film of oxide begins to form on the bright surface and by the color of this film the amount

of softening can be estimated. When the film first appears it is a very pale yellow to an orange, orange red, purple, and deep blue to a paler blue, after which the metal assumes its original color, and if further heat is applied it becomes red hot. If the metal is quenched at the straw-color stage it will only be slightly less hard than it was before "letting down," and if it is quenched at the pale-blue stage it will only be slightly harder than it was before the original hardening. By quenching at any of the intermediate points a corresponding degree of hardness may be obtained. The quality possessed by a carbon steel of responding to heat treatment as outlined above is one of the most important properties of this material.

Mild steel may be hardened on the surface by a process called "casehardening," in which the surface of the metal is really converted into a high carbon steel and then quenched. In this process the mild steel articles are heated to a red heat for several hours while in contact with a substance rich in carbon, such as leather charcoal, and while out of contact with the air. Cams, tappets, steel washers, and the races and balls of ball bearings are treated in this way, the result of which is to give a very robust structure to the article combined with extremely good wearing properties. The surface is practically glass hard, but the core is comparatively soft and has all the toughness of hardened steel. Certain steels, notably those composed of iron carbon and tungsten or chromium, are normally extremely hard and retain their hardness up to a dull, red heat. These are used for high-speed, heavy, lathe tools and for the exhaust manifolds of internal-combustion engines, where they frequently work at a dull red heat. Steels composed of iron, chromium, and vanadium, or iron, chromium, and nickel, or iron and nickel are extremely tough, and are not susceptible to fatigue. Such steels are used for connecting rods and crank shafts in internal-combustion engines. Similar steels with various percentages of nickel, chromium, etc., are used for cylinders of rotary engines, gear-wheel cams, inlet valves, etc. While the steel cylinders of several water-cooled stationary cylinder engines are machined from solid carbon steel (about 0.6 per cent carbon), in such cases the valve pockets are made separately and welded onto the cylinder by means of the acetylene flame, the water-jacket of mild-steel sheet being welded on afterwards.

Another important quality of steel is its property of carrying or retaining magnetism. The magnets of the magneto are usually referred to as permanent magnets: that is to say, they have been magnetized and remain magnetized. Such magnets are made of an iron, carbon, and tungsten steel carefully hardened to the maximum extent. Soft steels and irons may be easily magnetized, but do not retain their magnetism. Hard cast iron retains magnetism fairly

well, but can not be magnetized to the same extent as steel. The special magnet steels for permanent magnets permit of a high degree of magnetism and retain their magnetism to a remarkable extent. The armature of a magneto is composed of a very soft steel which is easily magnetized and demagnetized.

Cast iron.—The relatively large amount of carbon contained n cast iron (2 to 5 per cent) may be divided into two parts: that contained in the iron as a mechanical mixture in the form of graphite and that chemically combined with the iron. The bulk of the carbon present is in the form of graphite held in the pores of the iron. In structure, therefore, cast iron resembles a sponge of iron with the interstices filled with graphite. The presence of graphite obviously weakens the metal but it confers a special property which is extremely useful. Graphite is a lubricant so that cast iron may be looked upon, to a certain extent, as a self-lubricating metal. In practice it is found that cast iron surfaces run extremely well together in machinery. In practically all engines, with the exception of aero engines, the cylinders and piston rings are made of cast iron, and in internal-combustion engines it is usual to make the pistons also of cast iron, but since this metal is relatively weak, cast-iron pistons and cylinders must be relatively heavy so that in aero engines the pistons and frequently the cylinders are made of steel or aluminium alloy. Cast-iron piston rings are, however, nearly always used. Where steel cylinders are in use, they are sometimes fitted with cast-iron liners. Cast iron is a comparatively brittle metal, about half as strong as steel. It can not be hardened and tempered as in the case of steel, but very hard chilled castings may be obtained by using a special kind of mold. Soft or "malleable" iron castings are ordinary castings, which have been heated for a considerable period in contact with an iron oxide (red hematite). Cast iron is comparatively strong in compression and weak in tension so that no member of an engine which may come under tension is composed of cast iron.

Copper is a soft metal of extreme ductility. It is the best conductor of electricity with the exception of silver only. It is therefore used for electrical connections, magneto windings, etc. It is easily deposited or "plated" in an electrolitic bath, and in some aero engines the water jackets are formed of copper applied in this manner. Copper as opposed to iron becomes brittle after being heated, but may be made soft again by being "worked."

Brass, an alloy of copper with zinc, usually about two of copper to one of zinc (by weight). It is very easily machined and casts well.

It is about the same strength as cast iron and can be made hard and springy by rolling. It is used for obdurator rings, small parts of carbureters, magnetos, etc.

Bronze.—Bronzes of various composition are used as bearing bushes, tappet guides, small gear wheels, etc. Steel runs very well on bronze and the wear is not excessive. Ordinary bronzes are alloys of copper and tin, about 80 to 90 per cent of copper and 20 to 10 per cent of tin. A large percentage of tin giving a hard and more brittle metal. Ordinary bronzes also are not much stronger than brass, and phosphor bronze, containing about 2 to 4 per cent of phosphorus, is nearly as strong as steel. Phosphor bronze is also one of the best metals for bearing bushes.

White metal.—Connecting rods, bearings, and crank-shaft bearings are lined with white metal (if they are not of the ball-bearing type). White metal is composed of tin, copper, and antimony in varying percentages. A typical case is: Tin, 90 per cent; antimony, 7 per cent; and copper, 3 per cent. This gives a metal of low melting point, which is fairly hard and runs well on steel. In the event of a bearing tending to seize up, the heat generated will be sufficient to melt the white metal, and if the engine is immediately shut down no further damage will result.

Aluminum and aluminum alloys.—Aluminum weighs about 160 pounds per cubic foot and cast iron about 450 pounds per cubic foot. Cast iron is therefore about three times as heavy as aluminum. Pure aluminum is not so strong as cast iron, and it is often alloyed with heavier metals with the object of increasing its strength. Crank cases, gear boxes, and various fittings of aero engines are usually made of aluminum alloy, and in some cases the pistons are made of this metal. One of the difficulties in the use of aluminum for parts that are exposed to the high temperature of burning gases is that it has a comparatively low melting point (about 1,100° F.) and becomes mechanically weak when raised to a high temperature. For this reason the heads of aluminum pistons are well supported by means of internal webs, and in some cases also by an internal pillar resting on the gudgeon pin through a slot in the top of the connecting rod's small end. These webs, etc., also help to conduct away the heat from the piston head and so further reduce the risk of collapse. Another difficulty arises from the fact that under the influence of heat aluminum expands at nearly twice the rate of iron, thus necessitating a large clearance between the piston and the cylinder. It is not possible to solder aluminum in a satisfactory manner. Ordinary

solder is quite useless, and the special solder sometimes recommended requires special treatment and generally gives very poor results.

Notes on distortion.—All metals expand under the influence of heat. The amount of expansion is proportionate in any metal to the increase in temperature but differs for different metals. In the case of aero engines the working temperature is very high, owing to the high compression used, the high speeds at which these engines run, and the absence of large masses of metal which would help to conduct away the heat.

If the piston, cylinder, and valves, and, in the case of water-cooled engines, the water jackets, were made of the same metal or of metals expanding at the same rate, and if they were all raised to the same temperature expansions would give no trouble. In practice, however, not only are the parts made of different metals but they work at differing temperatures with the result that unequal expansion and subsequent distortion takes place.

The hottest part of an engine is the exhaust valve, but as this is a small symmetrical part, distortion is small. The exhaust-valve seating, however, will probably be hotter on one side than the other, and in a badly designed engine the distortion will be so great as to prevent the valve seating properly when the engine is running on low throttle.

The inlet valve is the coolest part of an engine, as it is in the path of the cold incoming mixture, and in some types of engines it is placed as close as possible to the exhaust valve with a view to keeping the temperature down. In some engines where the water jacket is of mild steel or copper sheet circumferential ribs or corrugations are made in the jackets in order that they may more easily follow the expansion of the cylinders. The piston head becomes very hot, as it can lose heat only by conduction through the skirt to the lower part of the cylinder wall and through the gudgeon pin to the connecting rod. The net result of distortion is that in practice clearances have to be made larger than would otherwise be necessary.

Fatigue of metals.—Metals which have been subjected to repeated stresses, such as those caused by vibration, become fatigued, their internal structure changes, and they are permanently weakened. The amount of fatigue depends upon the range of the stress or load, the number of times the material is subjected to the stress, and the rate at which the stress is applied.

The prolonged application of varying stresses very much smaller than the normal breaking stress of the material will induce fatigue and eventually bring about fracture.

V. THE GASOLINE MOTOR.

Introductory.—The object of a motor is to produce rotary motion either in itself or in a shaft. To get this motion the motor must be provided with—

(*a*) A piston which must be free to move up and down within a cylinder.

(*b*) A rod attached to the piston termed a connecting rod.

(*c*) Attached to the other end of the connecting rod a crank shaft.

(*d*) Attached to the crank shaft a flywheel or its equivalent.

The action of the motor is similar to the operation performed by a man turning a grindstone. The stone corresponds to the flywheel of the motor, the handle to the crank shaft, the man's arm to the connecting rod, and the power exerted in turning the stone to the exploded charge.

Power can not be produced without a cause. One of the most effectual methods of producing power is the expansion of gases. If a substance such as gunpowder is exploded in a cylinder with an open end (a gun for example) practically the whole effect of the explosion is felt at the muzzle; and if a bullet is placed in the gun in front of the gunpowder it is blown out with great force. This is exactly what happens in the gasoline motor—a mixture of gasoline vapor and air is ignited within the closed end of the cylinder and the force of the explosion drives the piston in front of it.

The piston in moving down the cylinder carries the connecting rod with it and the latter in its turn communicates its motion to the crank and so to the flywheel.

The flywheel once it has started rotating will carry on its motion for an appreciable time without any further application of power. Consequently it will communicate its motion to the crank and so to the piston, pushing the latter up the cylinder again. At the same time by forcing the piston upward the burnt gases are expelled from the cylinder through a suitable port or valve and by an arrangement to be described later. By the action of the flywheel the piston will again descend, traveling along the same path as it did when the mixture was exploded, but this time the piston is dragged instead of being pushed.

Immediately the dragging motion begins the port through which the burnt or exhaust gases escape is closed and a similar port or valve leading to the mixture and inlet pipe is opened. The downward motion of the piston, produces a partial vacuum at the head of the cylinder which results in a new charge of explosive mixture rushing into the cylinder through the port which has just been opened.

Just after the piston reaches the bottom limit of its stroke this port closes. The piston is then pushed up the cylinder once more and the mixture is compressed.

It may here be noted that within certain limits the greater the compression to which a mixture of gasoline vapor and air is subject, the quicker it will burn, and consequently the greater will be the force of the explosion.

When compression is at its highest, i. e., when the piston is on the point of reaching the top of its stroke, the mixture is ignited and the explosion occurs forcing the piston down.

It will thus be seen that one explosion and consequently one power stroke occurs every two revolutions of the crank or four strokes of the piston. For this reason the gasoline motor is described as working on the four-cycle principle.

The four-stroke cycle can be summarized briefly as follows:

(*a*) The suction stroke: The piston descends, inlet port or valve opens, and an explosive mixture of gasoline vapor and air is sucked into the cylinder.

(*b*) The compression stroke: Just after the piston has reached the bottom of the suction stroke the inlet valve closes, piston ascends and compresses the mixture (both inlet and exhaust valves being closed).

(*c*) The power or working stroke: Just before the piston reaches the top of the compression stroke the explosion occurs and the piston is forced down again.

(*d*) The exhaust stroke: Just before the bottom of the power stroke the exhaust valve opens. The piston ascends and the burnt or exhaust gases are forced out of the cylinder.

Suction stroke.—The intake pipe is full of an explosive mixture of gasoline vapor and air. The intake valve is open just after the piston starts descending in the cylinder. That is when the crank is about 5° to 9° past top dead center. The piston descending draws this explosive mixture into the cylinder. As it is descending very fast it causes a partial vacuum in the cylinder which the incoming gases have not sufficient time to fill up till after the piston starts ascending in the cylinder. So the inlet valve is not closed till the crank has rotated to about 18° past the bottom dead center. In some fast-running engines this angle is very much bigger.

The compression stroke.—As soon as the cylinder is as full of the explosive mixture as is possible and when the inlet valve is closed the piston still ascending the cylinder compresses the gases. At a variable point, normally about 26° before the crank reaches the top dead center, the explosive mixture is ignited. The mixture takes an appreciable time to burn and it is ignited so that when it is completely burnt the piston has finished its upward travel and is just starting to descend. This is called advancing the spark, and the amount of advance depends largely on the speed of the engine.

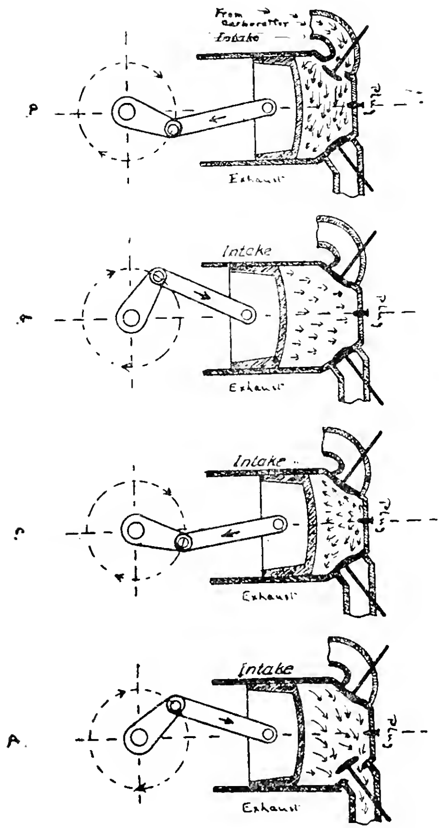
From Carburettor
Intake
Plug
Exhaust
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FIG. 20.

The power stroke.—As soon as the piston starts descending in the cylinder the gases begin to expand and push the piston down till the crank reaches a point varying between 45° and 75° from the bottom dead center. This is the power or working stroke. The exhaust valve is now open and the gases rush out of the cylinder. This early opening is called "giving lead" to the exhaust valve, and it is found very advantageous, as it insures an effective escape of the exhaust gases and consequent absence of pressure against

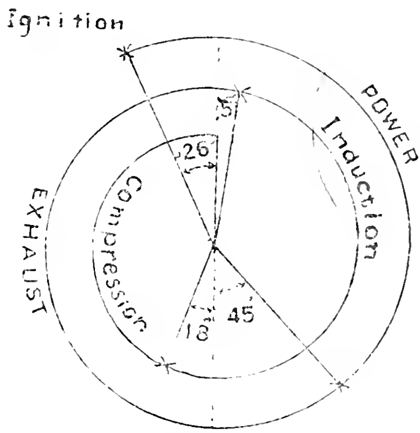


FIG. 21.

the piston on its return stroke. If the lead given to the exhaust valve is insufficient the engine is liable to overheat.

The exhaust stroke.—The exhaust valve remains open till the piston has passed to the bottom of the cylinder, ascended to the top and has just started to descend, that is when the crank has gone about 1° to 5° past the top dead center. The valve is closed when the piston is just past the top so as to insure that as much of the burnt gases have been cleared out of the cylinder as possible. There is now a very short space of time between the closing of the exhaust valve and the opening of the inlet valve. This is to make certain that the explosive mixture on entering the cylinder will not come in contact with the hot, burnt gases and so be ignited prematurely.

DETAILED DESCRIPTION OF THE WORKING OF THE GASOLINE MOTOR.

Arrangement of valves.—The majority of motors have two valves or ports for each cylinder, one to admit the explosive mixture and one to release the burnt gases after explosion. The former is termed the inlet and the latter the exhaust valve or port. The most common arrangement for aero engines is that in which the seatings for the valves are placed in the head of the cylinder. In ordinary motor-car engines the tops of the cylinders are cast with small extensions to one side, and in each of these extensions is the circular seating on which the head of the valve rests. The valve itself consists of a mushroom-shaped head with a long, thin stem, the whole being made in one piece.

The head has a beveled edge which fits closely onto the seating of the cylinder, being held down by a spring mounted on the stem. The bottom of the stem when the valve is closed and the engine is warm should be just clear of what is termed a "push rod." The push rod itself is raised and lowered by means of a cam, and so communicates its motion to the valve.

From the description of the cycle of operations it is clear that each valve must open and close once in every two revolutions of the crank. It will therefore be seen that the cams operating the valves must be worked at half the speed of the engine. This half-time speed is obtained by fixing to the crank shaft a gear wheel with, say, 16 teeth and providing the shaft carrying the cams with a gear wheel having 32 teeth. Then, when these two wheels are enmeshed and the engine is turning the cam shaft will be driven at half the speed of the crank shaft. Valves worked on this principle are called "mechanically operated valves." Exhaust valves are always mechanically operated. The necessity for this can be clearly seen, because at the moment it is necessary to open these valves they are being held tight shut by the pressure of the gases in the cylinder.

Inlet valves, on the other hand, are sometimes automatically operated—that is to say, they are opened by the suction effect caused by the piston moving down the cylinder, the exhaust valve of course being closed. A light spring is fitted to the valve stem to bring it back onto its seating at the end of the suction stroke. The automatic inlet valve is not as a rule considered advantageous because it is extremely hard to balance all the springs exactly so that a different amount of mixture is sucked into each cylinder. This causes bad running. The necessity for sucking also prevents the cylinder from getting as much of the mixture as it would if the valve were opened mechanically.

Owing to the very high pressure generated in the cylinder during the explosion it is very necessary that the valves should be so

designed that the pressure due to compression and explosion holds them on their seatings and so assists them to become gas-tight. For this reason valves are always designed to open inward. In some cases the inlet valve is placed close to and immediately opposite the exhaust valve so that the inlet gases pass over the exhaust valve and tend to keep the latter cool.

Valves are "timed" by setting them to open and close when the piston is a certain distance down the cylinder or when the crank of the engine is at a certain angle. All valve settings must be taken with the engine turning in the ahead direction, so as to avoid any errors due to play in the various gear wheels, etc. If the engine be turned too far ahead past any particular setting, turn it back more than the amount required before starting to take the readings again.

In order to obtain the direction of the revolution of an engine, turn it by hand. The inlet valve will open directly after the exhaust valve closes if the engine or crank shaft is being turned in the correct direction. By watching the inlet valves the order in which the cylinders fire can be determined.

When taking down an engine for examination and repairs it is absolutely necessary to note most carefully the relative positions of the timing gear wheels. They should be marked unmistakably (usually done by the makers) so that they can be put back in exactly the same relative positions as those in which they were found.

It has been said that the valves must fit very accurately onto their seatings. If the engine overheats, the valves are liable to warp, and this will prevent them fitting securely. In a well-designed engine this should not occur.

Sometimes little bits of carbon lodge between the valves and the valve seats. If this happens the hot gases rush across and in doing so will soon wear away the valve and the seat so that the compression in the cylinder becomes very poor.

In time the guides for the valve stems become worn and the valve instead of closing squarely will close on one side before the other. This also allows the hot gases to rush past the valve and wear it away.

From time to time the valves must be "ground in." This is done by coating the bevel of the valve with valve-grinding compound, which usually consists of a paste made of fine emery powder. The valve is now pressed onto its seat and turned around by means of a screw driver or special tool. It should be turned both ways, and after every turn or two should be lifted out of its seat. This makes the bevel even, so that the valve will close properly when turned in any position.

The valve, when properly ground, should make a gasoline-tight joint with the valve seat and can be tested for leakage with gasoline.

In many engines the push rod is done away with and the valves are operated directly from the cam through a rocking arm.

The cylinder.—The cylinders of an engine are usually made of steel. In some engines the cylinders are lined with cast iron and in others the cylinders may be made of cast iron altogether. The valve seats are either welded to the head or screwed in. There is a hole, or sometimes two, in the head of the cylinder screw threaded to fit the spark plug. In an air-cooled engine the cylinder will carry fins on the outside and in the case of a water-cooled engine the water jacket will be welded to the cylinder. In some engines the jacket is made of copper deposited electrically.

Near the bottom of the cylinder will be a means of attaching it to the crank case.

Most of the wear on the piston will come on one side, and after the engine has run over 100 hours this may become large enough to interfere with the efficiency of the engine.

The piston.—The piston can be described as a hollow cylindrical plug, to the interior of which is hinged the connecting rod. This is done by means of a short circular steel bar called the gudgeon pin, which is set diametrically through the piston and secured firmly to it. It is important that the gudgeon pin be held firmly in the piston and also in the lugs which hold it to the piston. The gudgeon pin is generally known as the wrist pin.

The piston is made of slightly smaller diameter than the cylinder (about 8/1,000 inch for a 4-inch cylinder) in order that it may move freely up and down the cylinder. This clearance depends on the materials of which these two parts are made. On account of this clearance it is evident that if other arrangements were not made the gases would leak past the piston, resulting in considerable loss of compression. This difficulty is surmounted by cutting one or more grooves around the outside of the piston wall into which "piston rings" are fitted. These rings are made of slightly larger diameter than the bore of the cylinder and are cut through sometimes diagonally and sometimes in the form of a step; thus, when the piston is in the cylinder the rings are compressed. At the same time they are constantly trying to expand to their normal diameter, with the result that they press tightly against the cylinder walls and keep the piston gas-tight. When two or more rings are employed the slits in the rings must not be vertically over each other. They must be set in different positions round the piston so as to avoid as far as possible the escape of any gases past the slits as would occur were they in line. The ends of these rings must be some distance apart when cold (about 3/100 inch for a 4-inch piston) so as to allow for expansion when the rings become hot.

The piston is made with a large skirt so as to have a large bearing surface on the cylinder walls. This also prevents the piston from tilting in the cylinder and helps to conduct away the heat from the piston head.

The bottom ring on the piston does not help much to seal the escape of gas but it wipes the excess of oil from the cylinder walls and prevents it from getting into the combustion chamber where it would carbonize and soot up the engine The top piston ring in some rotary engines is made of L section brass and is called an obdurator ring and acts in exactly the same way as does the cup leather in a pump.

The connecting rod.—The connecting rod is the bar which connects the piston to the crank pin. It is usually made of H section steel. The small end is fitted to take the bronze bearing of the gudgeon pin. The big end is fitted to take the big-end bearing, which consists of a cylinder of brass lined with white metal. In some engines of the

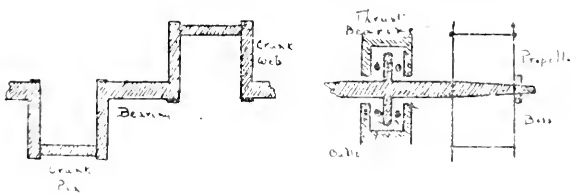


FIG. 22.

V type, only one of the pair of connecting rods bears on the crank pin. The other bears on the outside of the brass cylinder which holds the white metal. The two connecting rods thus work on the same pin.

In some rotary engines there is one rod called the master rod, and this is the only one which bears on the crank pin. All the other connecting rods are hinged to flanges on the master rod by means of wrist pins.

The rod being of H section must not be bent or twisted, as this will destroy its strength altogether.

The crank shaft.—The crank shaft, usually a steel forging, revolves in the bearings in the crank case. In multicylinder engines there is usually a bearing between every two crank pins. These bearings may be ball bearings or made of white metal. If the propeller is carried on one end of the crank shaft the shaft carries a thrust bearing, and this bearing is usually made to take the thrust in both directions, so that the engine may be used in a pusher or tractor machine.

The crank case.—The crank case, made of aluminum or, in the case of rotary engines, of steel, carries the cylinders and bearings for the

crank shaft and also carries the means of attaching the engine to the machine. The bottom of the crank case, except in rotary engines, is usually little more than a cover. It catches the surplus oil and sometimes carries the pumps which return this oil to the main oil pump. It is constructed of very thin material and engines must never be allowed to rest with their weight on the crank case.

The cam shaft.—The cam shaft carries the cams which operate the valves and as the latter are machined and solid with the shaft it is only necessary to time one cam and the rest will be automatically adjusted. In some engines the cam shaft carries the propeller, in which case it is furnished with the thrust bearing.

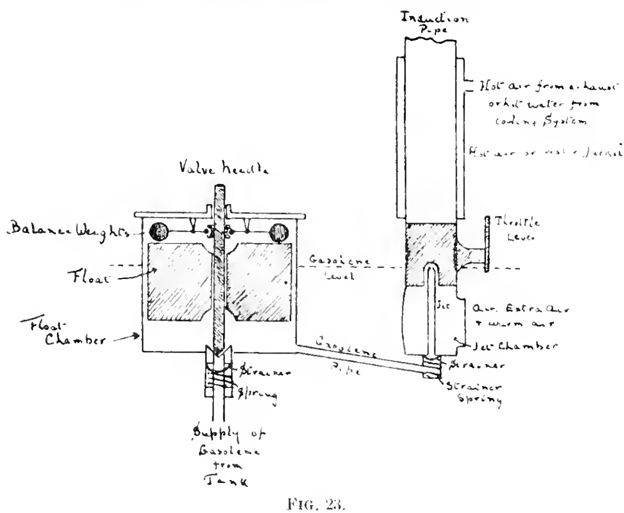


FIG. 23.

Gears.—Since the cam shaft runs at half the speed of the crank shaft it is necessary to gear them together. In case one of these wheels has to be replaced it should be remembered that the type of teeth in each wheel must be the same. If the teeth "bottom" there will be a tremendous vibration in the engine. If there is too much play between the teeth there will again be vibration with every little change of speed in the engine.

The carbureter.—This term is applied to the apparatus which is responsible for the regular supply of explosive mixture to the cylinders. One of the most important factors in the efficient running of a gasoline motor is the mixture. It is essential that the particles of gasoline vapor and air should be mixed as intimately as possible before they reach the cylinder. This is what the carbureter does.

The gasoline is led from the tank in the machine into what is termed the "float chamber." The object of this chamber is to keep the head of gasoline at a constant level. Inside the chamber is a hollow, brass float. Through the center of the float a needle passes which, when the gasoline has risen to a high enough level in the chamber, fits down into a seat in the gasoline pipe, thus cutting off a further supply. Just above the top of the float two balance weights are attached to the needle. The weights are pivoted about the needle and rest on the top of the float. Thus, as the level rises in the chamber the weights are pushed up and eventually allow the needle valve to fall back on its seat and so stop the supply of gasoline.

When the level of the gasoline in the float chamber falls the float drops and the balance weights acting on the needle valve lift it and allow a fresh supply of gasoline to come from the tank. Means are provided for lifting the needle off its seat by hand with a view to flooding the carbureter before starting the engine.

Carbureters must never be "tickled," as this wears the needle and makes it a bad fit on its seat. The needle should simply be lifted until the carbureter floods and then dropped.

A small pipe leads the gasoline from the float chamber into the jet chamber. Screwed into the end of this pipe is a vertical jet or nozzle. A set of jets with different-sized artifices can be obtained for use under varying atmospheric conditions. The top of the jet is arranged at such a height that it is very nearly the same height as the level of gasoline in the carbureter when the needle valve is closed and when the engine is in a normal condition. When the engine is running a partial vacuum due to the suction effect of the engine occurs round the jet and as the latter is small the gasoline is emitted in a fine spray, a condition which makes vaporization easy and consequently admits of a more perfect mixing with the air being sucked past the jet than would be the case if the gasoline were not vaporized. In some carbureters the vaporization of the gasoline is further assisted by warming the supply of air to the carbureter or jacketing the inlet pipe with hot air or water.

An inverted double cone is sometimes fitted round the jet to increase the speed of the air past it thereby still further reducing the pressure at this point. This also causes the difference of pressure on the gasoline in the float chamber and on the jet orifice to be increased, resulting in an increased flow of gasoline without interfering with the fineness of the spray. From the jet chamber the mixture passes along the induction pipe to the cylinder.

The action of the float can be likened to that of the automatic water system with its ball valve, while the action of the jet can be compared to that of a perfume spray.

The above are the essentials in the carbureter. The types in general use are more complicated and arranged for the suitable supply of gasoline vapor when the engine is running in dense air near the ground or in the rarefied air at a height.

The throttle and air valve.—The intake manifold is provided with a valve called the throttle, by means of which the amount of mixture admitted to the cylinders can be regulated. The more this valve is opened the greater will be the quantity of mixture admitted and the faster the engine will run. But the faster the engine runs the greater will be the suction effect at the jet; consequently the mixture will become richer in gasoline unless some means is employed for admitting more air. This is usually done by making the throttle act on both the inlet and discharge side of the jet or else by providing an additional air port the size of which, and therefore the quantity of air admitted, can be varied at will. Another method is to provide the extra air port with a spring which allows the port to open wider as the suction in the intake pipe increases.

The intake manifold should be as short as possible and should contain no sharp curves. It should be large enough and placed in such a position that all cylinders get the proper amount of mixture and so that one cylinder does not starve another.

The muffler.—At the end of the working stroke there is always a pressure in the cylinder above that of the atmosphere, and when the exhaust valve opens the gases rush out into the surrounding air at a high speed and with much noise. To reduce the noise a muffler is usually fitted, consisting, essentially, of a large vessel into which the waste gases pass direct from the engine. This vessel has a comparatively small exit hole for the gases to escape through to the atmosphere. The result is that instead of rushing into the air with a series of loud reports they escape in a steady stream. Baffle plates are often fitted in the muffler. The muffler reduces the power of the engine on account of the obstacles the gases meet on their way to the air. Consequently the piston has to do more work in forcing them out of the cylinder. In some engines it is possible, however, to fit an exhaust pipe in such a manner that one cylinder's exhaust assists another cylinder's exhaust.

Lubrication.—The lubrication of bearings is carried out by the formation of a very thin film of oil between the moving surfaces, which must be truly aligned and worked to a smooth surface, otherwise the film of oil will be broken at the "hard places," where the metal will become scored and the bearing probably overheated.

This film of oil is formed by the relative motion of the surfaces and the higher relative velocity and the more viscous the oil the more stable will the film become.

At low speeds, especially under heavy loads, the oil film is liable to be squashed from between the bearing surfaces and the lubrication will then largely depend on the "greasiness" of the surfaces. For this reason slow-moving toothed gears are better lubricated by a thick grease than any sort of oil.

At high speeds the film of oil will form between the moving surfaces even if the oil is fairly thin, but if the load is great the lubricant must be of a more greasy nature.

The animal and vegetable oils (i. e., castor, sperm, etc.) are more greasy than the mineral, and so must be used under heavy loads, even where the speed is high. If, however, the oil is forced through the bearings under pressure and is required to remain in contact with the working parts and to be used over and over again, mineral oils must be employed. Under these latter conditions vegetable and animal oils become acid and gummy and are therefore unsuitable.

Water is a very bad lubricant, since it is not viscous enough to form a film between moving surfaces, nor is it greasy, and so great care should be exercised to exclude it from all working surfaces.

The oils more commonly used are enumerated below. They all weigh rather less than water. The vegetable and animal oils are liable to "gum" by oxidation, but mineral oil is free from this defect and can be used again and again provided it is filtered each time before reuse. For these reasons mineral oil is employed for lubrication of all internal-combustion engines with the exception of the Gnome and one or two other types, where the oil simply passes through the engine and then escapes.

Mineral oil (light) for forced lubrication of bearings and low-powered internal-combustion engines (water cooled).

Heavy, filtered mineral oil for large internal-combustion engines (air cooled).

Mineral grease, vaseline, for preserving machinery and also the lubrication of the gear boxes, etc.

With internal-combustion engines, since the oil comes into contact with very hot surfaces, such as the piston, etc., an oil with a flash point of over 250° F. should be used. A fine mineral oil which is suitable for all bearings and working surfaces is generally employed.

The different methods employed for lubricating gasoline engines are many, but they can be classed generally under two heads:

1. Splash lubrication: In this method the engine is started with oil in the crank case up to a certain level. Additional supplies of oil are pumped into the crank case periodically when the engine is running. The crank throws of the engine revolve into the oil in the

crank case and splash it up to the piston and cylinder walls, etc. A baffle plate is usually fitted at the bottom of the cylinders, leaving just sufficient room for the travel of the connecting rod. This prevents overlubrication (and so carbonization) of the piston and cylinder walls and sooted plugs.

2. Forced lubrication: In the forced lubrication system a certain amount of oil is delivered by means of a pump to the main bearings, thence by means of a hole through the crank shaft to the main bearings, and then by a pipe or grooves along the connecting rod to the wrist-pin bearing. A separate lead also supplies the cam shaft and bearings and its gear wheels. Oil is also delivered under pressure to the valve-rocker arms. The oil streams into all the bearings and keeps them well lubricated, so that if well fitted there is extremely

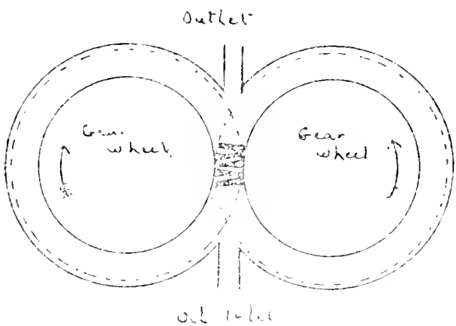


FIG. 24.

little wear in any of the bearings thus fed. The oil when it has passed through the bearings falls into a sump in the lower part of the crank case, whence it is pumped back immediately into the tank which supplies the main oil pump. No oil is thus allowed to collect in the crank case, so that the engine can be worked in any position without the cylinders at one end becoming overlubricated.

The oil used is mineral. As it is circulated round the system and used over and over again it is necessary to filter it between each round through efficient strainers so that no carbon or foreign substance is forced into the bearings. Any grit (carbonized oil, etc.) in the lubricant would of course at once produce local heating of the bearing.

A pressure gauge is provided with this system and from 5 to 55 pounds pressure per square inch is maintained by the pump, according to the type of engine. Should the pressure fall below this it is usually due either to the strainer getting choked and checking the

supply of oil to the pump or to the level of oil falling too low and causing loss of suction.

It may here be noticed that the pressure shown when the engine is first started will be considerably above that which may be expected after the engine has been running long enough to heat the oil.

Oil pumps.—The most usual oil pumps are of the plunger type or the gear type. They are worked through a gearing from the engine crank shaft. The plunger type does not call for much remarks. The gear works as follows:

Two gear wheels are enmeshed in a small case which fits closely around them. The oil is supplied to one side of these wheels. As they rotate they carry around oil in the spaces between the teeth from the intake side to the output side. When the teeth mesh the oil gets squeezed out of the spaces; it can not go back past the wheels because the case fits tightly, so it has to go through the output pipe. This type of pump gives a constant flow of oil and does not pulsate as does the plunger type.

Ignition.—The explosive mixture in the cylinder is ignited at the proper time by an electric spark which jumps across the poles of the "spark plug." This plug screws into the cylinder and it is important that no escape of gas can take place around the outside or inside of the plug. In some bad types of plugs the insulation loosens when the engine gets hot and this causes bad compression. The current which makes the spark is supplied by a generator or magneto, as described later.

Cooling.—Since the explosion takes place inside the cylinder itself, the temperature reached by the gases is very high. The cylinder walls have to be cooled by some external means in order to prevent them becoming too hot.

The effects of overheating are:

1. The metal is weakened very considerably so that all parts if not cooled would have to be very much thicker and heavier in order to prevent distortion or fracture.

2. The lubricating oil is burnt up and the cylinder scored by the deposited carbon; also there is a very great risk of one or more of the pistons "seizing up" in the engine and stopping it.

3. The charge may explode or preignite during the compression stroke, entailing a considerable loss of power.

One of two methods is usually employed for cooling the engine. The alternative methods are (a) water cooling, and (b) air cooling.

Water cooling.—Jackets through which water is kept circulating are constructed around the cylinder walls and ends and also around the exhaust-valve seatings. These jackets are either cast, welded, or electrically deposited around the cylinders. The hot water from

the jackets is led to a radiator which dissipates the heat through the atmosphere. This cools the water so that it can be used again. The usual method employed for circulating the water, especially with fast running engines, is to force the water through the jackets by means of a circulating pump driven by the engine itself.

In some cases the water is circulated automatically on the thermo-syphon principal, in which the fact that hot water is lighter than cold and therefore rises to the top is used.

The design of the engine should admit of no chance of air or steam pockets forming which might prevent a steady flow of water through the system. To prevent these pockets a small air cock is usually fitted at the highest points of any bends, etc. Small pipes are also often led from the tops of all such bends in the circulating water piping to the radiator to carry off any steam formed when the engine is running fast. Provision must be made for completely draining the jackets after using engines during a spell of cold weather so as to avoid any chance of bursting the cylinder jackets, pipes, etc., due to the water freezing.

There are a number of compounds on the market which can be put in the water to prevent its freezing, but many of these leave a deposit in the radiator and so prevent it working properly.

All cooling, though very necessary, is extremely wasteful, some 30 to 50 per cent of the total heat given out by the combustion of the fuel being carried away by it.

A small thermometer is attached to the radiator and placed where the pilot can see it so that he may know when his engine is too hot or too cold. He can keep his radiator at an even temperature by opening or closing shutters in front of it.

Radiators are placed either completely above the engine so that in case of damage by a bullet they will always have some water in them, or else right in front of the engine in order to do away with head resistance.

Air cooling.—In many gasoline engines the cylinders are kept cool by means of a stream of air impinging on their outer surfaces. In order to assist this dissipation of heat, gills or fins are formed on the outside of the cylinders which add to their external surface and so increase the rapidity of heat diffusion. Where the cylinders are small the heating surface per unit volume of cylinder capacity is sufficiently large to give cool running without other means than the ordinary rush of air past the cylinder due to the motion of the body. The larger the diameter of the cylinder the less will be the surface per unit volume. Larger cylinders will therefore require some additional means of cooling them such as a fan which forces air into a casing between the cylinders. The air escapes out of the

casing past the cylinders and in so doing cools them. In other engines the cylinders are kept cool by rotating them rapidly through the air.

One of the chief difficulties that have to be contended with in an air-cooled engine is the overheating of the exhaust valves. It is sometimes found convenient to provide a water jacket round the valve box and stem guides to keep these parts cool. The extra weight entailed is small and is, on the whole, quite justified by the results obtained. In some engines the inlet valves are placed close to and opposite the exhaust valves so that the incoming mixture passes over the exhaust valves, thus tending to keep them cool

VI. ENGINE EFFICIENCY.

The gasoline engine is simply a heat engine. It is supplied with heat in the form of a fuel and each pound weight of fuel gives up a certain definite amount of heat when it is completely burned. The amount of heat in, say, 1 pound of fuel can be accurately determined by actual experiment, 1 pound of gasoline being found to give up when completely burned about 22,000 British thermal units of heat.

If an auto tire be pumped up the temperature of the pump barrel will rise, but this is not entirely due to friction inside the barrel. In compressing the air work is done, thereby generating heat. If now the air is allowed to expand again to its original volume by passing through a small orifice it gets a high velocity, i. e., work is done by the air on itself, and it becomes cool again. This is exactly what happens in the gasoline engine. The explosion of the mixture generates a pressure which gives the heat a means of doing work and so transforming the thermal units obtained from the explosion into mechanical work.

For every 778 foot-pounds of work done on the piston 1 British thermal unit will have to be abstracted from the hot gases in the cylinder to supply the energy necessary for this work done.

The most usual way of expressing the efficiency is as a percentage of the heat available in the gasoline used that is turned into useful work by the engine.

The total heat received by the engine is dissipated in four ways:

1. Part does useful work on the piston in the cylinder.
2. Part escapes with the exhaust gases during the exhaust stroke
3. Part goes into the cooling water system (or to the surrounding atmosphere if the air-cooling system is used), provided to prevent the cylinders getting too hot and so gets lost so far as the useful work of the engine is concerned.
4. A very small part is lost by radiation; this may be neglected in comparison with the losses due to 2 and 3.

The efficiency will therefore depend on the magnitude of numbers 2 and 3.

In order that these losses may be reduced to a minimum, i. e., in order to obtain maximum efficiency, it is necessary—

(*a*) To have the mixture of correct strength and properly mixed.

(*b*) To have as large a ratio of expansion as possible consistent with the avoidance of preignition during the compression stroke.

(*c*) To advance the spark sufficiently far to insure the completion of explosion just before the commencement of the working stroke.

(*d*) The temperature of the cooling-jacket water should be kept as high as possible consistent with cool running.

These conditions will now be examined in detail.

A. Too rich a mixture and also too weak a mixture cause a slow rate of explosion. The component particles of the explosive charge will not mix sufficiently well to get rapid combustion; the flame of explosion will consequently only travel slowly through the charge. The result is that by the time the explosion is finished the piston will have completed a considerable fraction of its working stroke and the actual flame of explosion will therefore come into contact with a very large area of the cylinder wall. A large proportion of the heat will consequently be conducted through the cylinders into the water jacket.

B. When the piston is on its working stroke it is receding from the gases in the cylinder head; the gases therefore expand and cool down. Consequently it is necessary in order to get them as cool as possible before being exhausted that the working stroke should be as long as possible. The travel of the piston is the same on the compression as on the working stroke and the maximum ratio of expansion is practically the same as the maximum ratio of compression. Hence it follows that the maximum ratio of expansion is obtained when explosion is completed, just as the piston starts on its working stroke. At the same time it will be seen that with this condition of maximum ratio of expansion there will be a minimum loss of heat to the cooling system, for when the gases are at their highest temperature (i. e., when the explosion is just completed) they will be in contact with the minimum area of cylinder walls.

C. It must be remembered that compared with the movement of the piston explosion takes an appreciable time to complete. In order therefore that the explosion may be completed by the time the piston reaches the top of its stroke ignition must occur at the latter end of the compression stroke, i. e., the spark must be advanced. With the spark advanced and the mixture still being compressed explosion takes place very rapidly and therefore the gases when at their highest temperature are in contact with the cylinder walls for

the minimum length of time. If, however, the spark is advanced too far; i. e., with ignition taking place very early in the compression stroke explosion will be completed before the piston reaches the top of its stroke and a very much larger loss of heat to the cooling system will result; if the advance is very excessive the explosion will tend to prevent the piston from reaching the top of its stroke.

D. The amount of heat conducted from the cylinders into the cooling system will depend among other things on the difference of temperature between the cylinders and the cooling system. The larger the difference the greater will be the amount of heat lost.

Saving of weight.—The saving of weight in an aero engine is effected by using the strongest and lightest material and by means of the arrangement of the cylinders. Steel, which is light for its strength is used nearly all through except for those parts such as the crank-case cover, which is a cover only and bears no strength.

In a multicylinder engine if the cylinders are put in line, one behind the other, the crank case and crank shaft are very long and will have to be constructed heavily in order to prevent undue bending. Each connecting rod also will have to have a bearing of its own on the crank shaft. If the cylinders are now arranged as is done in a V-type engine the weight of the crank case and crank shaft will be greatly reduced because they will now be only about half the length they were before. The cranks will each take a pair of connecting rods so that there is a saving of weight in the main bearings. The shaft will not have to be any stronger because the cylinders will not explode at the same time, but at different times. The crank case may be still further reduced in size if the engine is made radial or Y-shaped. This type is used for all rotary engines. It is not altogether good for fixed cylinder engines on account of the difficulty in lubricating the bottom cylinder or cylinders efficiently. When mounted in a machine also these radial engines present a great head resistance, much more than do the narrow V-type engines.

Effect of centrifugal force.—It is a familiar fact that if a weight be whirled round at the end of a string it pulls outward and the force with which it pulls is described as centrifugal force. A striking example of centrifugal force is afforded by the case of a bucket of water which may be swung around in the same way as a weight without spilling the water. These facts are common knowledge, but it is not generally realized that the forces may be of such a magnitude that they have to be taken into consideration in the design of engines and in fact frequently form the controlling factor. As an example, we may take the case of the 80-horsepower Gnome engine, an engine of the rotary type, which has a diameter of approximately 2 feet 8 inches. When running at its full speed (1,200 revolutions per

minute) each pound of metal at the cylinder heads is pulling outward with a force of 65 pounds.

The existence of this large outward force gives rise to difficulties in connection with engine designs and in particular in connection with the valve gear of rotary engines. In some engines this force is neutralized by the fitting of balance weights, in others the valves have to be made especailly heavy to balance the tappet rods. It is very helpful in one respect and that is in connection with lubrication. In all rotary engines the lubricating oil is pressure fed into a duct or ducts inside the metal of the crank shaft. From this duct holes lead to the bearings, etc., and the oil from these parts is carried outward by centrifugal force to the outer parts of the engine. In rotary engines the surplus oil reaches the cylinder heads and is blown out with the exhaust.

In stationary engines the rotating cranks and crank pins are balanced in some cases by balance weights and in some cases by other cranks. The connecting rods and piston of stationary engines also require balancing and in the case of multicylinder engines it is possible and usual to arrange that the movements of the different pistons and connecting rods are such as to more or less completely balance each other.

Lightness in reciprocating parts.—Consider a single-cylinder engine driven around by some external means such as an electric motor. The piston is pulled and pushed on the connecting rod at the top and bottom of the stroke. The result is that there is a considerable unbalanced force exerted on the crank pin at these points. The upward and downward motion of the piston gives rise to vibration of the engine which at high speeds would be very marked if not balanced. In a single-cylinder engine this can be done only by the addition of extra balance weights opposite the crank throw. This, however, results in the introduction of new, unbalanced forces at right angles to the original unbalanced forces, and it is therefore not practicable to completely balance the piston of a single-cylinder engine.

The reciprocating parts of an engine are always made as light as possible in order that the forces to be balanced shall be reduced to a minimum. A heavy piston, for instance, will take a considerable force to raise it quickly up the cylinder and when it gets to the top it will again require a considerable force to stop it going up and to make it come down.

It must be remembered that, although the engine as a whole may be perfectly balanced, the forces exist within the engine and result in extra stresses and wear of the parts through which the stresses are transmitted.

Engine speeds.—A pilot must know, amongst other things, the normal running speed of his engine. The rotary engines run at about 1,200 revolutions per minute. The stationary engines in general run at higher speeds and in some cases the propeller is driven through a speed-reducing gear.

As a general rule the larger engines of a given class run at lower speeds, but the differences in speed between aero engines of different powers is small compared with the differences in other types of engines, owing to the fact that in aero engines extra power is mainly obtained by the adding of extra cylinders, whereas in the case of ordinary gas, oil, and steam engines extra power is mainly obtained by increasing the size of the cylinders. In other words, large cylinders involve low speeds and small cylinders permit of high speeds.

It may be assumed as a broad guiding principle that "the higher the speed the smaller the engine will be for a given power."

The power given by any one engine is proportional to the engine's speed; that is, an engine run at half its normal speed will give half its normal power (within practical limits). In the case of aero engines it is of course of the greatest importance to get the most power possible from a given engine, hence speeds are made as high as practically possible.

The disadvantages of high speeds are:

1. Extra vibration.
2. Extra wear of engine.
3. Extra stresses in the engine.
4. Greater difficulties in lubrication.
5. Greater difficulties in cooling.

Thus it is seen that engines should never be run at maximum for long periods unless there is some very urgent reason.

It will be found that if the speed of an engine is increased above a certain limit the power given by the engine no longer increases and in fact falls off with a further increase of speed. This is due to—

(*a*) The valves failing to follow the cams at very high speeds; and

(*b*) Reduction in the volume of the charge drawn in through the inlet and ejected through the exhaust owing to the very short time the valves are open.

In case (*a*) it may be thought that the difficulty might be overcome by fitting stronger valve springs. Such a method is not practical. It results in abnormal wear of the valve gear and fractured valves. The correct solution of the difficulty lies in the direction of lightening the valves, tappets, etc., and reducing the inertia of the moving parts. In some engines there are two or more inlet and exhaust valves in the cylinder head for this reason. In some engines also the cam shafts are mounted over the cylinders so

that tapper rods can be done away with. The valves are made as light as possible and each is operated through a short rocker arm by its own cam.

Propeller speeds.—The question of propeller and engine speeds in aircraft is roughly analagous to the corresponding problem in marine propulsion. The most efficient propeller runs at a comparatively low speed, and there is a certain difficulty in gearing the propeller to the engine without loosing efficiency.

In the case of rotary aircraft engines where the propellers are direct driven the speed (1,200 revolutions per minute) is too high for the most efficient propeller, and those used on rotary engines are made with a finer pitch than that required for best efficiency.

In some stationary aero engines the propellers are direct driven, but in the majority of cases they are driven at a lower speed than the engine. This is effected by running the propeller off the cam shaft, which is rotating at half the engine speed, or else by means of a special reduction gear. It should be noted that a speed-reduction gear uses up and wastes a certain amount of power and it also adds weight to the engine.

Another point is worth considering. As is well known the propeller torque or twisting force reacts upon the airplane and tends to turn it over sideways. This tendency is counteracted by wash in and wash out on the wings of the machine. If the propeller speed is high for a given power the torque is small and this effect is least, but if the speed is low the effect will be maximum.

Direction of rotation.—Normal engines rotate in a counterclockwise direction as seen from the propeller end, i. e., the engines are right-handed. In engines with speed-reducing gear, with some exceptions, the propeller rotates the opposite way and the engine left-handed.

VII. PROPELLERS.

The sole object of the propeller is to produce thrust. The thrust overcomes the drift of the airplane and draws (or pushes) the airplane through the air.

The thrust must be equal to the drift of the airplane at flying speed. If it is not equal to the drift, then the airplane can not secure its proper speed.

The thrust will be badly affected if any of the following conditions are not as they should be:

Pitch-angle.—The propeller screws through the air, and its blades are therefore set at an angle. This angle is known as the pitch-angle, and must be correct to half a degree. It is of course smaller toward the tips of the blades, just as in the case of the pitch-angle of a marine propeller.

Pitch.—The pitch is the distance the propeller will advance through the air in one revolution, supposing the air to be solid. As a matter of fact, the air is not solid and gives back to the thrust of the propeller blades, so that the propeller does not travel its full pitch. Such "give back" is known as slip. For instance, the pitch of the propeller may be perhaps 10 feet and the propeller may have a slip of 2 feet. The propeller would then be said to have 20 per cent slip.

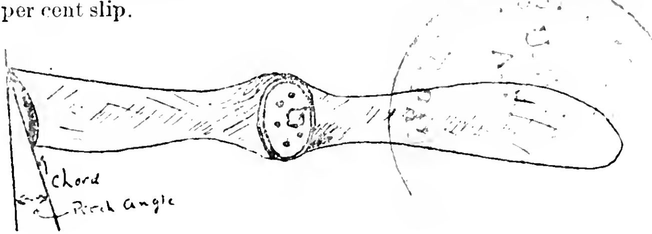


FIG. 25.

To test the pitch-angle the propeller is mounted on a shaft, the latter being mounted upon and at right angles to a beam. The face of the beam must be perfectly straight and true.

Now select a spot some distance (say about 2 feet) from the center of the propeller and by means of a protractor find the angle the chord of the blade makes with the beam. Then lay out the angle on paper, thus:

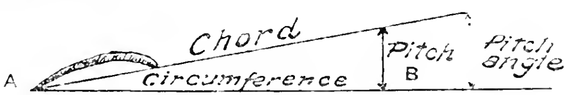


FIG. 26.

The line marked "Chord" represents the chord of the propeller. The line marked "Circumference" represents the face of the beam. The angle the two lines make is the angle you have found by means of the protractor.

We will suppose, for the sake of example, that the point at which you have taken the angle is 2 feet from the center of the propeller. Find the circumference at that point by doubling the 2 feet (which is the radius) and then multiplying the result by 3.1416, thus $(2'+2)\times 3.1416=12.5668'$; i. e., the circumference at that part of the propeller.

Bring it down in scale and mark it off from the point A and along the circumference line. Now draw the line marked "Pitch" from B (the end of the circumference measurement of 12.5668′) and at right angles to the circumference line.

The distance from B to the chord line is the pitch of the propeller at that point.

It must agree with the specified pitch of the propeller, which should be marked on the hub. If it does not do so, then the pitch-angle is wrong. This may be due to—

1. The propeller blade being distorted.
2. To faulty manufacture.
3. To the hole through the propeller boss being out of place.

Degree of error allowed.—An error up to half a degree, more or less, from the correct angle may be allowed, but if it is greater the matter should be reported and the propeller changed. The propeller should be tested as explained above at points along the blades, the first point about 2 feet from the center of the box and the others about a foot apart.

Length.—The propeller should be carefully tested to make sure the blades are of equal length. There should not be a difference of more than seven-sixteenths of an inch.

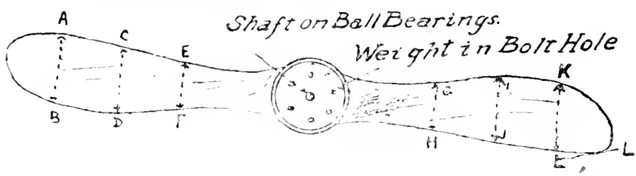


FIG. 27.

Balance.—The prevailing method for testing for balance is as follows: Mount the propeller on a shaft. The shaft must be on ball bearings. Place the propeller in a horizontal position, and it should remain in that position. The propeller should also remain stationary when placed in a vertical position.

If a weight of a trifle over an ounce placed in a bolt hole on one side of the hub fails to disturb the balance, then the propeller is unfit for use.

The above method does not, however, test for the balance of centrifugal force, which comes into play as soon as the propeller revolves. The test for centrifugal balance is as follows:

The propeller must be kept horizontal, and while in that position weighed at any fixed points, such as A, B, C, D, E, and F, and the weights noted. Now reverse the propeller and weigh at each point again. Note the results. The distances of corresponding points on either side of the center of the hub should be equal. The first series of weights should correspond to the second series, thus: Weight A should equal weight F; weight B should equal weight E; weight C should equal weight D.

There is no official ruling as to the degree of error allowed, but if there is any appreciable difference the propeller is unfit for use.

Surface area.—The surface area of the blades should be equal. Test with callipers. (See fig. 27.)

The distance A–B should equal K–L; the distance C–D should equal I–J; the distance E–F should equal G–H.

There is no official ruling as to the degree of error allowed; if, however, there is an error of over one-eighth inch, the propeller is really unfit for use. The corresponding points on each side of

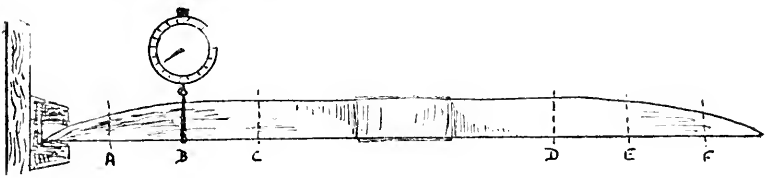


FIG. 28.

the propeller must, of course, be exactly the same distance from the center of the propeller.

Camber (i. e., curvature).—The camber of the blades should—

1. Be equal;
2. Should decrease evenly toward the tips of the blades; and
3. Its greatest depth should at any point of the blade be at about the same proportion of the chord from the leading edge as at other points.

It is difficult to test the top camber without a set of templates, but a fairly accurate idea of the curvature underneath the blade

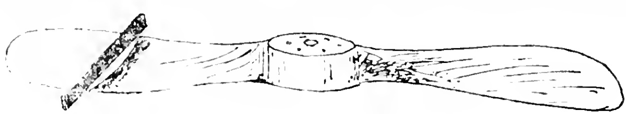


FIG. 29.

can be secured by slowly passing a straightedge along the blade, the straightedge (a steel rule will do) being held at right angles to the length of the blade and touching both leading and trailing edges, thus—

The concave curvature can now be easily seen, and as you pass the straightedge along the blade you should look out for any irregularities of the curvature, which should gradually and evenly decrease toward the tip of the blade.

Straightness.—To test for straightness mount the propeller upon a shaft. Now bring the tip of one blade round to graze some fixed object. Mark the point it grazes. Now bring the other tip round

and it should come within one-eighth inch of the mark. If it does not do so it is due to the propeller being distorted or to the hole through the boss being out of place. In either case it is unfit for use.

The joints.—The method for testing the glued joints is by revolving the propeller at 5 to 10 per cent greater speed than it will be called upon to make in flight and then carefully examining the joints to see if they have opened. It is not likely, however, that you will have the opportunity of making this test. You should, however, examine all glued joints very carefully, trying by hand to see if they are quite sound. Suspect a propeller in which the joints appear to hold any thickness of glue. Sometimes the joints in the boss open a little, but this is not dangerous unless they extend to the blades, as the bolts will hold them together.

Condition of surface.—The surface should be perfectly smooth especially toward the tips of the blades. Some propeller tips have a speed of over 30,000 feet a minute and any roughness will produce a bad drift or resistance and spoil the efficiency of the propeller.

Long grass on the airdrome and mud and water will take all the polish off the propeller tips and sometimes do serious damage.

Mounting propeller.—Be careful to see that the propeller is mounted quite straight on its shaft. After mounting test it the same way as was done for straightness. Before reporting the propeller as faulty make certain that the bolts have been screwed up equally all round and that some are not too loose or too tight.

Care of propellers.—The care of propellers is of the greatest importance, as they are very likely to distort and loose their correct pitch-angle and straightness.

1. Do not store propellers in a very damp or very dry place.
2. Do not store them where the sun will shine on them.
3. Never leave them in a horizontal position or leaning up against a wall.
4. They should be hung on pegs, the latter at right angles to the wall and the position of the propeller should be vertical.

If the points noted above are not attended to you may be sure of the following results:

1. Lack of efficiency, resulting in less airplane speed and climb than would otherwise be the case.
2. Propeller "flutter;" i. e., vibration, which will cause the propeller to distort and possibly collapse.
3. A bad stress upon the crank shaft and its bearings.

Swinging the propeller.—Before swinging the propeller (i. e., rotating it to start the engine) it is necessary to know in which direction it should be turned. Unless the propeller has been fitted to the engine incorrectly it is quite easy to see which way to turn it.

Grasp the trailing edge of the blade; the trailing edge is much thinner than the leading edge. Move the propeller slightly so that you may "feel" the compression. The rotation of the propeller will now be in such a direction that the flattest side of the blade will engage the air and press against it.

As a rule when the propeller is fitted to the crank shaft it revolves in an anticlockwise direction when viewing it from the position you stand in to swing it.

When it is fitted to another shaft which is geared to a crank shaft, then, as a rule, it revolves in a clockwise direction.

VIII. STARTING THE ENGINE.

Sound footing.—First of all make sure that the ground just in front of the propeller affords you a good sound footing. Should your foot slip when swinging the propeller the result may be very bad for yourself.

Now place the blocks in front of the wheels of the machine and lay out their cords toward the wing tips. These blocks should always have cords attached; otherwise sooner or later a mechanic will step into the propeller when it is revolving.

One mechanic should be at each wingtip and should grasp the bottom of the outer struts to steady the airplane when the engine is running. They should not hold the leading edge of the plane, because if they do they will probably leave oily marks on the fabric, and the dope will slack off in these places. These mechanics will pull the blocks away when the pilot signals for such action.

There should be not less than two mechanics at the tail end of the fuselage in order to keep it down when the engine is running. In many machines the tail may be kept down by pulling the control lever well in toward one.

Rotary engines.—In the case of some rotary engines it is necessary, after ascertaining that the switch is off, to prime the cylinders with gasoline. This is done by squirting gasoline through the exhaust port. Great care should be exercised to make sure that the squirt is clean. Never lay it on the ground. The top of a gasoline tin is a good and convenient place.

Switch off.—Before attempting to rotate the propeller always make sure that the ignition switch is off. Otherwise the engine and propeller may start unexpectedly with disastrous results to the starter. There has been more than one fatal accident due to carelessness in overlooking this point. Never touch a propeller without saying "switch off." Always see that the ground wire is connected.

Gasoline on and air closed.—Now ascertain that the gasoline is on and the air closed. The air is not really quite closed, but is partly

cut off so that the mixture may be rich in gasoline in order to facilitate the first few explosions.

Rotate propeller.—Now swing the propeller round. This will turn the engine, and the effect of the descending pistons will be to suck the mixture into the cylinders.

Contact.—Now sing out "on" to the pilot. He will put the ignition "on" replying to you "on."

Swing propeller.—Now one good downward swing of the propeller blade and *stand clear*. If the engine fails to start, ask the pilot to "switch off" and go through the same operation again.

Starting magneto.—In some engines a starting magneto may be used instead of swinging the propeller, in which case, after sucking in the mixture, the propeller should be left in such a manner that one cylinder is ready to fire. This can be felt by gently moving the propeller up and down.

Self-starters.—If a self-starter is used it is done in the same manner as is done on a car. In small, fast machines the use of the self-starter does not repay the loss of efficiency due to weight.

Danger of "kicking back."—When swinging the propeller be careful to stand clear of it. There is often a possibility of the engine "kicking back" and suddenly turning the propeller the wrong way around. This is usually due to ignition occurring early, i. e., before the piston arrives at the top of the cylinder, and if the engine is revolving slowly the momentum of the moving parts (crankshaft, propeller, etc.) may not be sufficient to carry it round in the right direction. The result of this is that the piston never gets to the top of its stroke but descends again, driving the crank shaft back and round in the wrong direction. For this reason when you have decided to swing the propeller give it one good downward swing. Do not give any small preliminary swings after you have called "on."

Signals.—1. The pilot when ready to start will wave his hand from side to side. This is the signal for the blocks under the wheels to be pulled away smartly by means of the cords attached to them.

2. Now the pilot waves his hand in a fore and aft direction. This is the signal for everyone to stand clear without a moment's delay, and is especially meant for the mechanics at the tail of the fuselage.

While the pilot has his hand still raised he gives a look around to see that everything is clear. He then taxis to the place from where he is going to start.

IX. DEFECTS IN THE ENGINE.

Defects in the engine, their causes and remedies.—There are three essential conditions to be fulfilled in order that an internal combustion engine may be started and then be able to carry on working. These are:

1. The mixture must be of the correct strength and its components properly mixed.

2. There must be sufficient compression to bring particles of the mixture into intimate contact with each other and so render them explosive.

3. There must be some method of igniting the charge at the right time of the stroke, i. e., somewhere near the end of the compression.

If the engine refuses to start after flooding the carbureter, opening the air inlet, and switching on the current, or putting other ignition devices into gear, etc., proceed to test, if all these conditions are being fulfilled, as follows:

1. *Faulty mixture.*—A frequent trouble with the mixture is due to omission to turn on the gasoline or to the gasoline pipe being choked. Examine the gasoline pipe and filter and clean if necessary. If gasoline be pressure fed, there may be insufficient pressure in the tank to force the gasoline into the float chamber of the carbureter. In any case of the engine refusing to start or suddenly stopping always *first look* to the gasoline supply by ascertaining if the carbureter will flood. A choked spray or water in the carbureter may also be the cause of the trouble. Examine and blow through the jet; remove the float and see if any water or dirt is present at the bottom of the float chamber; if so, drain it out. A piece of copper tubing fitted too tightly into an india-rubber connecting pipe may fray the rubber and so cause the pipe to become choked. When starting the engine by hand, it is often necessary to flood the carbureter so as to insure gasoline coming into contact with the air going to the cylinders past the top of the jet, or else to squirt some gasoline through the compression cocks into the cylinders before starting. This latter is termed "priming the cylinders." In cold weather less air is required, since the increased density of the air allows a greater weight to pass through the air inlet. Failure to close the extra air inlet before trying to start will very often prevent the engine from starting. When starting up with a cold carbureter in cold weather the gasoline will tend to condense in the intake pipe; a rag wrapped round the inlet pipe will be of assistance in getting the engine under way. The needle valve in the float chamber may be warmed so that the float has to be raised above its normal level before it allows the needle valve to drop and shut off the gasoline supply. The needle valve itself may also leak due to wear or dirt lying on its seating. Both of these will give too high a level of gasoline in the float chamber and thus in the jet; hence the mixture will become too rich in

gasoline. If excessive the carbureter float chamber will overflow. The float may be leaky and hence become too heavy; this if only a small amount of gasoline has leaked into it will produce the same results as above. If much has entered, the float will not shut the needle valve at all and the carbureter will therefore flood badly and overflow. For this reason in engines where a flame is highly dangerous the overflow and all drains should be led to a funnel well away from the carbureter, so that a back fire or flash back will not cause a conflagration. Flooding of the carbureter may also be caused by the upper part of the needle valve being too neat a fit in its guide, or by the needle valve being too light for its work and so unable to shut on its seating against the head of gasoline. A piece of waste left in the air-inlet pipe after an overhaul is by no means an uncommon cause of failure of an engine o start.

2. *Compression.*—If the engine is turned by hand and the compression cocks at the top of the cylinders are open during the compression stroke, air will be forced out of these cocks at high speed if the degree of compression is anything like good. It should be noted that small leaks in the inlet and exhaust valves, sparking plug terminals, etc., will not appreciably affect compression when actually running owing to the very small fraction of a second occupied by the compression stroke, though, when testing by "hand revolution" the effect may be very marked especially in large cylinders. The power required to turn the engine round by hand will also indicate roughly the compression in the different cylinders. Should the compression be bad examine for the following faults:

A. Leaky or broken piston rings. The piston rings should bear against the side of the cylinder over their whole circumference. When testing for this the cylinder walls should be covered with a thin coat of rouge or red lead and the piston rings put inside and moved up and down. The marking on the rings will indicate whether they are bedding properly and also is there is insufficient spring left in the rings. When fitting new rings allow one thirty-second or one sixteenth inch space between the butts of these rings when in the cylinder to allow for expansion. The rings may be gummed into their slots in the pistons by foul oil. Kerosene injected into the cylinder and left for a few minutes will dissolve the oil and release the rings.

B. The valve and valve seat may be pitted or worn. The seat in the cylinder and the beveled edge on the valve should be ground together with emery powder, coarse powder being used to start with and the very finest when finishing. If a groove has been cut on the valve during the process of grinding in skim the valve up in a lathe

and then finish off by grinding into place with very fine emery powder. The valve or its seat may be warped as a result of overheating; if only slightly grind in as above; if very bad new valves will have to be fitted from the spares and the seat will have to be reseated. The valve spindles may be too tight a fit in their guides due to too big a valve stem, or the presence of oil and carbon in the valve guide. Kerosene will clean the latter. If the valve stem is at fault a rub with emery cloth will often give sufficient slackness. Insufficient or no clearance may have been left between the valve stem and the tappet. This is easily adjusted, once discovered. The timing of the cam shaft may be wrong. This must be checked. When checking take all settings with the engine moving in the ahead direction only.

3. *Ignition.*—Failure of electrical arrangements are dealt with under "magneto."

4. *Back firing.*—This occurs when the charge explodes, immediately it enters the cylinder through the open valves and back fires into the intake manifold and so to the carbureter which it is liable to set alight if there be any gasoline in it. The causes of back firing:

A. The most common cause is through a very weak mixture being supplied to the cylinder. The charge does not explode and is still burning when the inlet valve opens on the next inlet stroke. This may be due to the gasoline supply cock being only partly open, or the strainer or jet becoming choked by grit, dirt, etc.

B. Carbon deposits get formed on piston heads and walls of the compression space if the mixture supplied be constantly too rich in gasoline; this carbon cakes and becomes heated to incandescence and so ignites the incoming charge immediately on contact taking place.

C. A leaky exhaust valve, a weak spring, or a sticky spindle on an exhaust valve would allow hot, exhaust gas to be sucked in from the exhaust pipe during the suction stroke and mix with the incoming charge which it raises to ignition temperature causing a premature explosion.

D. Water in the gasoline will sometimes be the means of producing a back fire due to the same cause as "A."

E. Electric ignition leads not being joined up correctly or one of the high-tension leads making electric contact with another and causing a spark to occur a revolution too soon, i. e., just as the fresh charge is entering the cylinder.

5. *Misfiring.*—This is said to take place when the charge is drawn into the cylinder and compressed, but passes through the whole working stroke without any explosion taking place. In a multi-

cylinder engine the unexploded charge as it leaves the cylinder and comes into contact with the hot exhaust gases may cause an explosion to occur in the muffler or exhaust pipe. Misfires are caused by—

A. The mixture containing too much or too little gasoline, thus forming a nonexplosive charge. Misfires due to this cause usually occur in all or pairs of cylinders; if the latter the prime cause will probably be traced to a faulty designed intake manifold or badly adjusted carbureter. Heating the intake manifold or air supply to the carbureter may, however, overcome it.

B. Poor compression due to causes already mentioned. Misfiring in this case occurs in one or more cylinders independent of the relative position with regard to the inlet pipe.

C. The mixture containing a quantity of exhaust gas and so being too weak. Cause, a leaky exhaust valve. The leaky exhaust valve would also prevent good compression so that this really comes under the same heading as "B."

D. Defective ignition. With modern high-tension magnetos defective spark-plugs are the most common cause of misfire.

6. *Preignition.*—This happens when the mixture is fired on the compression stroke (usually without the aid of a spark) thereby tending to make the engine run backward. This is often, quite wrongly, called "back firing." This may be caused by—

A. The ignition spark being advanced too much when starting. Explosion will occur before crank is over dead center, making the engine run backward a few revolutions. This should always be very carefully guarded against when starting an engine by hand, as the wrench given to the starting handle when preignition occurs is sufficient to sprain or even break the operator's wrist.

B. A hot piston or cylinder, due to the spark being too far retarded, causing much of the heat of the explosion to pass into cylinder walls and piston head. This causes the fresh mixture to become overheated during compression and so to explode prematurely. Preignition, even if it does not actually force the engine round in the wrong direction, may cause very heavy "knocking" in the bearings, which will strain the engine and reduce its speed. If it be very excessive it may easily produce fracture of some part of the mechanism, usually the crank shaft.

C. Overheated piston, etc., due to too weak a mixture. This is not an uncommon result, in cold weather, of too economical a carbureter.

7. *Smoky exhaust.*—A smoky exhaust may be caused by too rich a mixture or by overlubrication; the excess of oil supplied to the piston and cylinder is sucked up the sides of the piston during the suction stroke and partially burnt. A too rich mixture will usually

leave black specks on one's hand if it is put into the smoke of the exhaust.

8. *Overheated cylinders.*—Having the mixture too weak, i. e., containing too much air, is by far the most common cause. Too much gasoline will also overheat the cylinders, though to nowhere near the same extent as too little gasoline. The ignition too far advanced or too far retarded is also a cause of the cylinders running hot.

X. IGNITION.

There are two types of ignition arrangements:

1. Battery.
2. Magneto.

The first system has been largely superseded by the second, but owing to the fact that it gives practically a continuous spark without the assistance of the engine it is retained in many motor-car engines to facilitate starting when the engine is cold. The magneto is usually run off the engine so that the engine must have a certain speed to make a spark. Sometimes a starting magneto turned by hand is fitted in order to make a spark while the engine is at rest. Both systems are eventually dependent on the same principle, which is converting a low-power electric current to a high-power one which is strong enough to jump across the point of a spark plug and make a spark.

To make a spark there must be a generator for the electric current, a circuit to carry the current, and a gap for the current to jump across and create the spark. The circuit must be insulated to prevent loss of current.

If an electric current passes through a conductor (i. e., a piece of wire), as soon as the current commences to flow a magnetic field is created around that conductor from which lines of force will move out radially. The magnetic field around a single wire would not be very strong so that the conductor is wound in a coil or many coils to give the requisite strength. The coils must be insulated so that the conductor of one coil does not actually touch another. If this conductor is wound round a core of soft iron the magnetic field will be stronger still. When the current is switched on lines of force will spring out from this central core and when the current is stopped these lines of force will fall back again.

If lines of force cut a conductor or if a conductor is moved through a magnetic field, a current of electricity is produced in the conductor and this is called an "induced current." Supposing we wind wire outside the coils of wire we have referred to above, making sure that the wire is well insulated, every time the lines of force spring out from the central core they will cut the outside coils of wire and pro-

duce in the conductor an electric current. This happens every time we either make or break the connection of the inner circuit. This inner circuit is called the "primary circuit" and the outer one the "secondary circuit." It should be noted that a current is induced in the secondary circuit only at the moments of "make" and "break" because, as we have said, the current induced in the secondary depends on the cutting of the conductor by the lines of force and this only happens when they spring out or fall back toward the central core.

So long as lines of magnetic force are cutting the conductor it does not matter if the magnet or conductor are moving; in either case a current will result.

Magneto ignition.—The fundamental principle on which the magneto works may be expressed simply as that in which a closed coil of wire rotates within the field of force of a magnet and cuts through the lines of force. A current is induced twice per revolution of the coil.

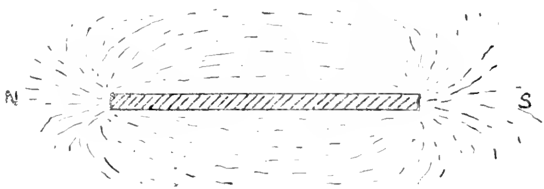


Fig. 30.

The field of force exerted by a magnet is easily demonstrated by placing a sheet of paper over the poles of the magnet and then sprinkling iron filings on the paper. The filings will take up clearly defined positions around the poles.

Some metals retain their magnetism permanently, while others lose it at once. An example of the former is hardened steel, and of the latter soft iron. Advantage is taken of this fact in the magneto.

The magneto consists essentially of two or more horseshoe-shaped magnets placed side by side (in some magnetos there is a pair of double magnets side by side and in which one magnet is placed on top of the other). The ends of the magnets are termed "poles," i. e., north and south. Attached to the poles by screws are pieces of very soft cast iron, which are cut away into semi-circular form inside the horseshoe. It is across this "polar space" that the magnetic lines of force are concentrated. Within the horseshoe and the semi-circular pole pieces an "armature" is made to rotate. This "armature" consists of a shuttle-shaped core around which primary and secondary windings are coiled exactly in the same manner as in an induction coil. The "armature" is made up of a number of soft

iron plates in order that it may obtain and lose its magnetism very quickly.

As the "armature" rotates in the magnetic field it is evident that there are two positions in each revolution when the coils are being cut by the largest number of lines of force.

These are called the "maximum positions," and it is at these points that the current is induced in the primary winding. A new field of force is then created, due to the current passing through the primary, and this field is further strengthened by the core of the "armature" becoming itself a magnet. These new lines of force cut the secondary winding and induce a current in that, adding still another "field." The current of the primary is then broken at the "contact breaker" and the field belonging to the primary collapses, but slowly owing to the influence of the lines of force of the secondary, the current still tending to flow in the same direction. At this point

Fig. 31.

the "condenser" comes into play and a sudden reversal of the direction of the current in the primary occurs. So rapidly do these motions take place that the spark occurs at the plug at the same instant as the breaking of the primary circuit. It is thus seen that two sparks are obtained every revolution of the "armature" and the speed of rotation therefore has to be regulated to the number of cylinders in the engine.

Although there are only two positions in which the maximum number of lines of force cut the "armature" windings, yet immediately before and after these positions are reached there will still be enough lines of force cutting the primary to give a current. It is this fact which allows the ignition to be advanced or retarded at will by altering the moment when the current in the primary is broken.

The primary current is broken mechanically by a fiber stop on the end of a bell-crank lever carrying one-half of the "contact breaker." Rollers are fixed in the circular track passed through by the fiber stop in its revolution and as the top passes them the bell-crank lever is swung about its fulcrum, parting the two screws forming the sides of the "contact breaker." One end of the primary circuit is

"grounded" to the "armature" core and the other connected to the fixed half of the "contact breaker," which is carried on the "armature" spindle. The secondary circuit is usually connected to one end of the primary so as to be "grounded." The other is connected to a slip ring, where a brush collects the secondary current produced by the rupture of the primary current and passes it on to the distributor and thence to the spark plugs. The distributor is on the same principle as that described above for "accumulator" ignition. The "condenser" is connected in parallel with the two sides of the "contact breaker," i. e., the two plates are connected to the two parts between which the break in the electrical circuit occurs.

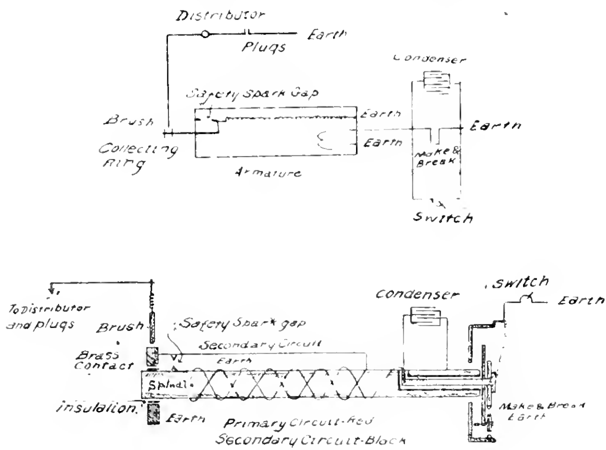


FIG. 32.

To protect the insulation of the "condenser" from being pierced by the high voltage when one of the leads to the plug is withdrawn a "safety spark gap" is provided near the brush collector on the slip ring. This acts as a sort of "safety valve," for as soon as the voltage or "electrical pressure" rises too high a spark jumps across this spark gap, thus relieving the electrical pressure in the circuit. To stop the flow of current to the plugs in order, for instance, to stop the engine, the end of the primary winding leading to the "contact breaker" is connected by a carbon brush to a switch. By "closing" this switch this end of the primary winding is put to "earth" and the coil is thus turned into a closed circuit. Hence no "make" and "break" can occur in the primary and so no current is generated in the secondary circuit. When, however, the switch is "opened" the "contact breaker" again comes into action and the

magneto if revolved will give a spark. A terminal is always provided for this purpose on the magneto.

There is another kind of magneto in general use in which the "armature" itself does not revolve. A shuttle of soft iron is revolved in between the "armature" and the pole pieces. This shuttle distorts the magnetic field and thus draws the lines of force across the conductors wound round the "armature." Maximum current is given when the lines of force are springing back to the normal, and this occurs four times during a revolution.

Faults in ignition.—The failure of electrical arrangements may be due to—

1. Battery and coil ignition (if fitted).
2. The magneto ignition.
3. The spark plugs.

If dual ignition is fitted—that is, if there are two coils or two magnetos—try each in turn. One of the two probably will be found correct, and the fault thus partly located. Should both fail, remove the spark plugs and clean them with gasoline, replace, and try again.

When testing the two ignitions, the spark plugs can be short-circuited to the cylinders by means of any steel tool having a wooden handle to hold it by, e. g., a screw driver. If a spark be observed between the end of the screw driver and the cylinder, it will show that the high-tension current is at any rate reaching this point, and the length of the spark will denote its intensity. This indicates that the ignition is producing a spark and hence the fault must be in either—

A. The plug itself; or

B. In the timing of the magneto or its electrical connections, or in the batteries (if fitted).

To test for "A," faulty plugs, the plug should be removed and tested by passing a high-tension current through it in air under about 100 pounds pressure per square inch. If a good spark passes across the plug terminals and no signs of "flashing" occur elsewhere in the plug, it may be assumed to be in working order. It is no use testing the plug electrically under atmospheric pressure, as the resistance of the spark gap under pressure is so much greater than under atmospheric conditions that a flaw in the insulation which may have sufficient resistance to prevent a short circuit occurring under these conditions will break down under the moderate pressures obtained when actually working.

With rotating cylinder engines the terminal at the end of the plug is pulled outward with considerable force. In plugs in which mica is used as the insulation there is a danger of the center pole of the plug becoming bent toward one side of the plug and thus short-

circuiting the current when the engine is rotating. Any plug in which the central pole is bent or at all loose should be at once changed or adjusted.

To test for "B," timing magneto and "distributor," if the fault is elsewhere than in the plugs test the timing of the ignition as follows:

Turn the engine by hand slowly and note the timing of the spark in the different cylinders, observe the crank angle (and inlet and exhaust valves) at the instant when the two sides of the "contact breaker" come apart. This indicates that a spark will occur at this point in the cycle. If this is correct, the various ignition leads should then be traced most carefully to make sure that they are connected up to the right cylinders and securely fastened to their respective terminals. If no spark appears while testing the terminal of the spark plug by short-circuiting, examine all the electrical connections and see that none of them have come adrift or have been connected up to the wrong terminals.

A common cause of the magneto refusing to work is a short circuit to "ground" on the switch connection. This prevents the primary current being broken by the "contact breaker" and consequently the production of a spark.

The platinum points on the "make" and "break" may want adjusting or the coils, condenser, or wire leads in the "armature" may have become short-circuited.

When machines are kept in tents, especially where the engine is mounted behind the magneto, it often happens that the magnetos become damp and refuse to spark properly. This may be prevented by wrapping up the magneto at night, but it should be remembered that damp will often deposit inside a covering of this kind after the machine has been up in the cold and then lands and is put into the warm tent.

Defects which may occur when certain specific conditions are observed.—

1. A fouled plug: To find out which cylinder it is, slow down the engine by throttling as much as possible and then short-circuit each plug in turn to the cylinder. When one of the nonfaulty plugs is thus shorted the engine will slow down considerably, but when the foul or shorted plug is treated in this manner no difference is detected in the running of the engine. The temperature of the cylinders will often indicate the defective plug. Replace the plug with a new one.

2. Faulty distributor: Examine the carbon brush on the distributor and see that no oil has got to it. If there are signs of grease, clean it off with gasoline before replacing it. The carbon brush may have worn a groove round the distributor and the metal strips leading to the plug terminals may have got masked by the insulation. The best remedy for this is to turn up the inside of the cylinder carrying the distributor segments in a lathe.

3. Defective insulation on connecting wire to plug: If the wire carries a high-tension current a spark will probably be seen at the point where the insulation has given way. Indications will be the same as in "1." Examine the insulations carefully and replace the wire if necessary by a new length. Should the flaw in the insulation be small, a repair can be made with India-rubber solution and sticky tape. With stranded wire care should be taken to see that all strands are neatly housed in the terminal. It sometimes happens that one strand escapes and is short-circuited by the vibration of the engine, which causes intermittent missing and is sometimes hard to detect.

4. Faulty condenser: This ought not to occur in magnetos where a safety gap is provided to prevent too high a voltage being generated in the secondary circuit. It is usually indicated by sparking at the platinum points of the "contact breaker." Should the platinum points of the "contact breaker" be worn and pitted the same indications will be present so that it is as well to examine these platinum points first of all, and then if necessary to file them square and smooth, afterwards adjusting them to the correct distance apart at break—0.4 millimeter (16/1000 inch).

5. If all the cylinders fire weakly on the magneto circuit, examine the "contact breaker" and its adjustments.

6. No spark obtainable with the magneto circuit: See that the wire from the long-contact terminal to which the switch circuit is connected is not short-circuiting to the frame. The ground brush at the back of the rocking lever of the magneto "contact breaker" may be oily and so preventing the magneto secondary circuit from being completed.

7. No sparking at any terminal: A terminal of the distributor circuit has probably come loose or the wire short-circuited. Examine both carefully. The switch contacts should also be examined in all these cases.

8. The magneto refusing to stop, producing secondary current when switched off: This is probably due to oil having got underneath the carbon brush on the short-circuiting terminal at the end of the long-contact screw of the magneto "contact breaker." Remove the cover over this latter and clean the end of the brush and the face it bears on with gasoline, then replace.

XI. MOTOR TRANSPORT.

Engines.—In general motor-car engines are governed by the same principles as those applicable to air engines. The general chapter on engines must therefore be read in conjunction with this chapter. In addition the following points should be noticed:

A. Bearings should normally be examined after 10,000 miles. They may only require to be tightened up or they may be badly worn, thus necessitating remetaling.

B. New piston rings will require to be fitted at this period.

C. Whenever, for any reason, an engine is taken down it is advisible at the same time to grind in the valves, clean the pistons and cylinder heads, and clean all oil leads and filters. When reassembling the engine it is necessary to use new washers and packing throughout.

D. As all motor cars are fitted with variable ignition, care must be taken in tuning to allow sufficient "advance" and "retard" to be given on the ignition quadrant. In cases where independent magneto and battery ignition are fitted, each system must be adjusted so as to spark at the same point in the cycle.

Routine examination.—Periodical inspections of the car or truck must be made and the following points seen to:

Every time the car is used—

A. Tires correctly inflated and spare wheels in place, and tools for changing wheel or rims (jack and brace).

B. Radiator and gasoline tank full. Carry spare can of gasoline and strainer.

C. Sufficient lubricating oil in the pump or reservoir and that the feeds work freely.

D. Batteries properly charged and coil working.

E. Brakes working properly.

Every day before duty—

A. All the above points.

B. Oil holes on steering arms, knuckles, universal joint, etc., cleaned and oiled. This should be done after the car has been cleaned.

C. Grease cups on springs and shackles screwed down and properly supplied with grease.

Weekly—

A. Spark plugs and ignition looked over, magneto oiled and cleaned.

B. Examine water joints, see pump packing does not leak, and also that the radiator is tight.

C. Refill axle caps and examine clutch leather.

D. Open gear box and see that there is sufficient grease.

E. Changing tires about on wheels if uneven wear is noticed.

F. Examine body work.

Monthly—

A. Grind in valves (or after 1,000 miles running).

Care of grease and oil cups.—There are several parts on the car which require regular lubrication and which are not supplied automatically. These parts are generally equipped either with grease cups or oil holes. Particular note should be made of oilers on the spring hangers, universal joints, steering pivots, knuckles, steering-gear box, and such like. It is also necessary periodically to introduce some lubricant between the laminations of the springs.

Drivers of motor vehicles should make themselves thoroughly acquainted with all the grease and oil cups on their cars, and must systematically keep them supplied. The frequency of the application of oil or grease will depend on the amount of running.

Care of clutch.—The clutch may want a little attention. If a leather clutch is fitted and the leather comb can be got at, it may be brushed over with at least one coat of castor oil, the latter being allowed to soak in. This should be done when the clutch is "fierce" owing to the leather becoming glazed and hard. It does not follow that a new clutch leather is necessary when a clutch is not giving satisfaction. Sometimes it will be found that a shoulder of about one-sixteenth inch deep has worn on the old leather. This should be carefully trimmed off with a sharp file, which will give the leather a new life. This allows the comb to go farther home, giving a closer contact between the surfaces.

Especial detail to watch is to see that the copper rivets are well below the surface of the leather. If they become flush with the leather, the result would be a nasty gripping or even difficulty in disengaging. A metal to metal clutch requires to be cleaned out occasionally with kerosene. A hole is generally provided for the purpose in the clutch casing. If the clutch takes hold with a jerk, a little thin mineral oil will put it right.

Gears.—The gear box should be regularly inspected to see that there is an ample supply of lubricant, but not an excess. It is quite unnecessary to fill up the cases, as this will only result in the gear grease flooding out at the joints and bearings and making them a receptacle for mud and dust. The amount of lubricant used should be sufficient to cover the lower teeth of the gears; the rest will look after itself (see differential gears).

Differential gear and chains.—The differential gear transmits the power from the speed-change gear to the rear axle of the car. Cars which are made with chain drive to both wheels have the differential gear arranged on the countershaft at the ends of which the chain sprockets are fitted. Usually she differential and chain-speed gear are fitted in the same case.

Chains require to be renewed occasionally and taken up as they wear. Clean with kerosene and lubricate with graphite on a brush. Links of various lengths can be added.

Care of brakes.—Attention to the brakes is very important. They should be adjusted as closely as is permissible, the jaws being set so as just to clear the drums but not to set up any permanent friction. A screw adjustment is provided for this purpose. Too much clearance lessens the responsiveness of the brakes, especially in an emergency. The rods actuating the brakes should be carefully examined from time to time for any signs of weakness. Particular attention should be paid to insure that the jointing pins have split pins properly fitted.

Cleaning and washing cars.—The car ought to be washed down as soon as it comes in, without giving the mud a chance to set. On no account should dust, dirt, or mud be brushed off. It must, in the fullest sense of the term, be washed off or else the paintwork will be ruined. If a hose is available, it will be very useful in getting the mud off the under parts of the car and will save a lot of time and labor.

In using the hose for the outside of the car (that is, for the wheels and body work in general) the following points should be observed:

A. Care must be taken that the water does not go anywhere but where it is intended to go. It should not be splashed about in every direction.

B. A strong pressure of water from the nozzle is of considerable advantage in cleaning the underparts of the car, where the mud is generally heaviest, and in cleaning the underside of the mud guards.

C. When dealing with the paintwork, however, a strong pressure of water is quite likely in removing the gritty particles at the same time to force them over the paintwork and scratch it. Apply the water with little force, but in plenty. If this is done when the car comes in wet, the mud will be speedily and easily removed. If the mud has been allowed to dry, the water must be poured over it, so as to soften it first of all. Afterwards it will gradually be carried away as the water runs over it. On no account should the mud be rubbed off. Brushing or rubbing the mud off, even if it is wet, will cause scratching and deterioration of the paintwork.

D. When all the dirt and mud has been soaked off, the surface can be gone over with a wet sponge, using clean water.

E. Oils and grease are bad for the paintwork, and care must be taken that neither gasoline, kerosene, or lubricating oil is allowed to remain on any part of the paintwork.

F. When dealing with a car which is soiled with dust, the same care must be used in attempting to rub it off, the surface should be gone over first with a full sponge and finished off as before.

Care of tires.—If the following points are attended to the life of tires can be increased considerably:

A. Cuts, even surface cuts, require vulcanizing. This keeps out the water.

B. Tires must be kept up to pressure, 20 pounds to each inch cross section, i.e., $36 \times 4 = 80$ pounds.

C. If possible, keep two spare wheels, so that repairs can be carried out on one while the other is ready for duty.

D. Watch wheels for alignment. If a tire shows abnormal wear, look to the axles or distance rods.

E. Do not apply brakes abruptly, except in emergency. A rapid "pull up" takes a good deal of mileage off a tire.

XII. INSTRUMENTS.

The barometer.—The mercurial barometer is the standard instrument for measuring the pressure of the atmosphere. In this instrument the pressure of the atmosphere is compared with the pressure at the base of a column of mercury of known height.

If a tube from which the air has been exhausted is placed with its open end in a small cistern of mercury, the pressure of the atmosphere will force the mercury up the tube until the pressure at the level of the surface of mercury in the cistern, due to the column of mercury in the tube, is equal to that of the atmosphere acting downwards on the surface of the mercury in the cistern. The pressure of the atmosphere is conveniently given in terms of the length of this column of mercury.

An actual barometer consists essentially of the exhausted tube dipping into a cistern of mercury as detailed above. Alongside the glass tube is fixed a scale over which moves a vernier. The vernier is set exactly level with the top of the mercury.

As the mercury rises in the exhausted tube the level of the mercury in the cistern will fall, so that if the scale be fixed its readings will no longer give the true distance between the surface of the mercury in the tube and of that in the cistern. To eliminate this error one of two methods may be adopted. In the Fontin barometer the bottom of the cistern is made of wash leather and can be raised or lowered by means of a screw until the surface of the mercury always just touches a fixed mark. In the Kew pattern barometer the length of the divisions of the scale on the tube is slightly altered so that it always reads the correct height without adjusting the mercury in the cistern.

Errors and their correction.—

A. Temperature: The first thing to be allowed for is the temperature of the barometer. If the temperature rises it affects the barometer in two ways—

1. The mercury expands and therefore rises in the tube. This is equivalent to an apparent increase of pressure.

2. The scale against which the height of the mercury is measured expands, causing an apparent decrease of the height of the mercury or a fall of pressure.

To eliminate the effects of change of temperature the readings of the barometer are always corrected to what they would be if the whole barometer were at 32° F. This correction depends on the actual temperature at the time, the coefficient of expansion of mercury, and that of the scale.

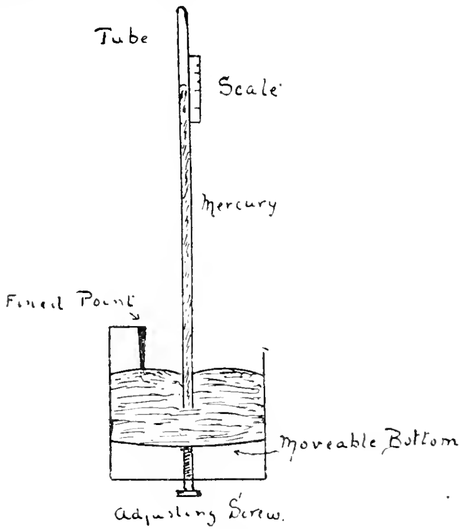


FIG. 33.

B. Height: With a view to comparing the pressures at two or more stations, as, for example, in order to construct a daily weather map, allowance must be made for the different heights of the stations. The higher the station the less will be the pressure. For purposes of comparison, therefore, the reading of the barometer is always corrected to what it would be if the station were at sea level. The amount to be added is given by the formula:

$$\log B - \log b = \frac{h}{60369}\left[1 + 0.00204(t - 32)\right]$$

where B is the pressure at sea level, b the pressure at the station, h height of the station in feet above sea level, t temperature of the air in degrees Fahrenheit.

For convenience tables giving this correction can be constructed. but a special table must be made for each station.

As far as an aviator is concerned a rough rule for height within a few thousand feet of the ground is as follows: The column of mercury falls 1 inch for every 1,000 feet of height.

C. Index errors: The scale may not indicate the true distance from the surface of the mercury in the cistern.

D. Scale errors: The graduations of the scale may not be the right distance apart.

These two errors "C" and "D" are best found by having the instrument tested against a standard barometer and corrections must be applied to allow for them.

E. Imperfect vacuum: If a small quantity of air be left in the tube above the mercury it will cause the reading to be too low, the

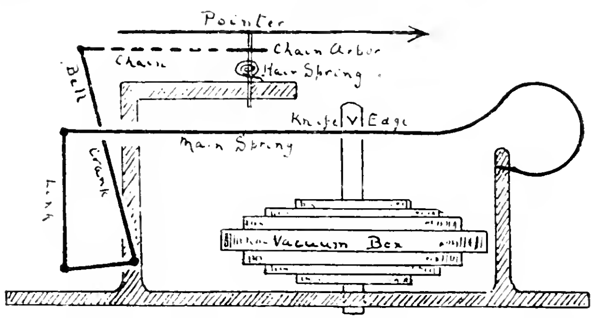


FIG. 34.

amount varying with the temperature and height of the barometer. This can easily be tested by tilting the barometer gently until the mercury reaches the top of the tube. If it hits the top with a sharp click the vacuum may be considered good.

Aneroids and barographs.—The mercury barometer is the only really reliable instrument for measuring the atmospheric pressure acurately. It is, however, not a portable instrument and for many purposes an aneroid is more convenient. This instrument contains one or more flexible metal boxes from which the air has been partially exhausted. The pressure of the atmosphere on the outside is always tending to compress the sides of the box while a spring placed inside tends to push the sides out. Hence, as the atmospheric pressure changes the box will be expanded or compressed. By means of suitable levers the motion of the box causes a pointer to move over a graduated scale. This scale is generally graduated so that it gives pressures in terms of inches of mercury as measured on a mercurial

barometer. For air work it is usually graduated in hundreds and thousands of feet.

Errors: It should be noticed that both the original setting of the instrument as taken by the makers from the standard barometer and the scale value depend on the adjustment of the instrument. The scale value, i. e., the size of the graduations of the scale, is generally accurate, but the absolute value of the pressure in inches of mercury given by an aneroid can seldom be relied on. This latter value will vary if either the scale or the pointer be permanently moved relatively to each other (e. g., by altering the adjusting screw or moving the needle). Therefore, the aneroid is used, it is for reading differences of pressure and *not* the absolute pressure at any given moment, unless they have been calibrated with reference to a standard mercury barometer.

Aneroids are frequently subject, also, to errors due to changes of temperature. As the temperature rises the elasticity of the spring inside the flexible boxes decreases and the boxes are compressed more than they would otherwise be. This causes an apparent rise of pressure. Even many so-called "compensated" aneroids are subject to some error from this cause.

Any form of barometer which gives a written record of the changes of pressure is known as a barograph. These are generally of the aneroid type. Instead of the motion of the aneroid boxes being communicated to a simple pointer moving over a scale, it is communicated to a pen moving over a chart wound round a revolving drum driven by clockwork. Otherwise the principle is the same.

Such barographs are subject to the usual errors of aneroids, and in addition errors may be introduced by excessive friction, either in the levers or between the pen and paper. If as the barometer rises or falls the pen moves up or down in a sudden step there is almost certainly friction. Variation of pressure is almost always gradual. The friction may frequently be minimized by reducing the pressure of the pen on the paper; but sometimes the pivots of the bearings need adjustment. In this latter case the instrument should be sent back to the makers.

Aneroids and barographs are frequently used to measure difference of heights. This is done by measuring the differeuce of atmospheric pressure at the two places to be compared. The difference of pressure is due to the difference of the weight of air above the levels of the two places. The actual difference of pressure corresponding to any difference of height is given by the formula above. From this it is seen that the difference of pressure depends to some extent upon the temperature of the air and upon the mean pressure.

On aneroids and barographs which are provided with a scale showing heights it is necessary when fixing the scale to decide upon a

mean pressure and temperature of the air. When the pressure and temperature of the air differ from the assumed mean it is obvious that the height reading obtained will not be quite correct. This error may amount to about 4 per cent on account of difference of temperature and to about 4 per cent on account of the difference from mean pressure. Some aneroids, however, are now made in such a way that the errors due to the pressure being different from the mean are very greatly reduced.

Aneroids in an airplane are the only means of obtaining the height above the ground. The scale is set at zero before the machine leaves the ground and the heights shown by the aneroid are those above the level of the airdrome. This should be borne in mind when bomb dropping because the target may be very much higher or very much lower than the airdrome and this will make a large error in the fall of the bomb. Then again, for bomb dropping at great distances the pressure of the air over the target may be very different from the pressure above the airdrome when the machine started.

There is usually a great lag in the instrument which makes the readings too low when ascending and too high when descending. For this reason one can never use an aneroid to tell the height at which one should straighten up to land a machine. This should be borne in mind if one has to make a landing in the fog or in darkness. When the aneroid shows zero on account of a lag the machine is probably a little below and may strike the ground at any moment.

Anemometers, or air-speed indicators.—The anemometer in general use up to about 15 years ago was that known as the Robinson anemometer. This instrument consisted of four arms which were capable of turning about a vertical axis. Each arm carried a hemispherical cup at its end. In consequence of the wind having more force on the concave side of the cups than on the convex side these cups were driven round with a speed proportional to the velocity of the wind. A counting gear was attached to show the number of times the cups turned round. This instrument will only give satisfactorily the mean wind over a given time. For most aviation purposes the gustiness of the wind or when flying the sudden changes in speed is perhaps the more important matter. The Robinson anemometer gives no indication of this and is therefore of little use for aeronautical purposes.

A much more useful instrument is that designed by Dines. In this anemometer a wind vane is mounted so as to turn round freely with the wind. The front part of the vane is in the form of a tube, the opening of which is always kept facing the wind. This is the pressure opening. The hollow vane is connected through an air-tight joint to a pipe leading to the recording apparatus below. The

wind blowing down the vane increases the pressure inside the tube. A second pipe led from the recording apparatus opens just below the vane in a series of small holes arranged symmetrically round a vertical tube. As the wind blows past these holes it produces a small suction.

The two tubes are connected to some form of pressure gauge which indicates the velocity of the wind. The gauge in the self-recording instruments consists of a vessel floating in water. The inside of the float is connected to the pressure tube from the vane and the space between the outside of the float and the containing vessel is connected to the suction tube. The principle is the same as that of a gasometer, assuming that the latter were inclosed in a case. As the difference of pressure between the air in the two pipes increases the float is raised out of the water. A pen attached to the float records the velocity at each instant on a chart rolled round a drum driven by clockwork. The pressure produced by the wind is proportional to the square of the velocity so that the float must be made of a special shape if its movements are to be proportional to the square root of the pressure, i. e., equal to the velocity and *not* to the pressure, which would be the case if the float were cylindrical.

This instrument requires very little attention. In setting up its indication should be compared with some form of pressure gauge to see that the readings are correct.

The density of the water varies with the temperature and this causes the zero of the instrument to change. To correct this the float is weighted with a few shot so that the zero is always correct. It is also important to see that the level of the water is kept constant at the fixed mark (the float being in the zero position when this is tested).

The pressure produced by the wind is proportional to the density of the air. Any cause which makes the density of the air change will therefore alter the indicated velocity. The density of the air is changed by variations of temperature and pressure. But the changes produced at the earth's surface from these causes are too small to be important for matters connected with aviation. When, however, instruments on the same principle, e. g., Pitot tubes and air-speed indicators are taken up in airplanes to show the velocity of travel through the air the change produced in the readings by the decrease of pressure, and therefore the density of the air, may be appreciable. Thus, at 5,000 feet the indicated speed will be 7 per cent below the true speed. In addition to recording the velocity of the wind the Dines instrument may also be fitted to show the direction. In this case a rather larger vane is provided than is usual with the smaller instrument and it is mounted on ball bearings. The vane is connected to a rod which passes vertically down to the

recording apparatus. This consists of a drum with two spirals which engage two arms connected to the recording pens. As the vane turns round the drum is also turned and moves the pens on the paper. This type of anemometer is generally designed so that it records both the velocity and direction of the wnid on the same chart.

Air-speed indicators on machines.—In all modern machines the indicator usually consists of a pressure head mounted to point straight ahead on one of the outer struts of the machine, and this is connected by aluminum tubing to the gauge on the instrument board of the machine. This head is very much the same as that of the Dines tube. One tube points straight to the front, the other tube is arranged to have no pressure in it. The first is the "Pressure" tube and the second the "Static" tube. The tubes are arranged this way to insure that there will be no unknown pressure acting against the pressure of the air as would be the case if the tube opened

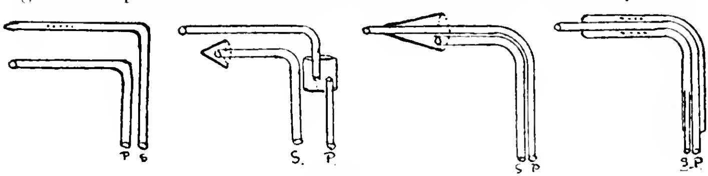


FIG. 35.—PRESSURE HEADS.

P=Pressure tube. S=Static tube.

just anywhere in the machine. The gauge consists usually of a diaphragm of some material which can be moved backward and forward as the pressure increases or decreases. The center of the diaphragm is attached by a silk cord or by gears to a pointer and this pointer indicates the pressure of the air at the pressure opening.

The readings of the gauge can be checked by connecting the pressure opening to a U tube containing liquid. If a pressure be applied so as to work equally on both the gauge and the liquid, the liquid will rise to a certain height and the gauge will show a certain reading. The air speed is shown by the following formula:

$$S=K\sqrt{\frac{h}{r}}$$

where S equals the speed in miles per hour, r equals the density of the air, k equals a constant depending upon the shape of the pressure head, h equals the height of the liquid in inches (water at normal density).

From this it is seen that the gauge must be graduated to suit the head; that is, a "mark 3" head should not be used with a "mark 4" gauge. Also, at a height, the readings will be far lower than the actual speed.

These instruments have also a certain lag so that they do not show small quick changes in speed. A pilot can stall his machine and regain flying speed without the instrument ever showing that he has lost his flying speed. These instruments also may be set to a wrong zero so that a pilot should never fly by his air-speed indicator only. These indicators simply show large mean changes in the speed of the airplane and are best used as a guide only.

The pipe connecting the pressure head with the gauge must be air-tight. The joints are made with rubber tubing which frequently rots.

Some instruments, such as the Pitot tube itself, depend on a height of liquid or on unbalanced parts in the gauge. These instruments are only accurate when flying in a straight line. If turns be made the unbalanced portion of the instrument is pulled down by centrifugal force so that a wrong reading is given. Thus, the liquid in the Pitot tube shows zero when a fast spiral is made although the speed may be 60 or more miles an hour.

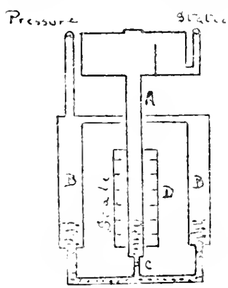


FIG. 36.

The Pitot tube air-speed indicator.—The tube consists essentially of the following:

A glass tube "A" is placed in the middle of a U tube "B" and is connected to it by a very small pipe "C." The U tube "B" is connected to the pressure tube of the head. The glass tube is connected to the static part. The tubes are filled with a colored liquid which reads "zero" on the scale "D" when the machine is at rest. When the machine is in flight the pressure acts on the liquid in the tube "B" and forces it up the glass tube so that it registers the speed which is read off from the scale. The small tube "C" is in order to keep the liquid from moving up and down too quickly so that a reading can easily be taken. The disadvantage of this is that the instrument does not register quick changes of speed.

There are two branches to the tube "B," so that when the machine tilts the liquid rises in one branch and falls in the other, but the reading of the liquid in the glass tube is not altered.

This instrument is affected by centrifugal force when a turn is made.

The Venturi tube.—The head of this tube consists of a pipe bent to face the direction of flight and a second tube which is fitted into a suction arrangement shaped thus:

This head is connected to a suitable gauge so that the air speed can be read by means of a pointer.

The advantage of this type of head is that the constant "k" is five times as great as that of the Pitot type head. This means that it is easier to make, small errors making only one-fifth the difference.

Types of gauge.—There are three types in general use at present. Any one type can be used for nay type of pressure head but it must be remembered that the readings will have to be changed.

The first type consists of a metal box across which is stretched a rubber diaphragm, thus:

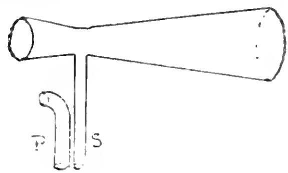


FIG. 37.

The pressure part of the head is led to the gauge above the diaphragm and the static part of the head to the part below. Varying pressures make the diaphragm move up and down and these movements correspond to the speed of the airplane. The center of the diaphragm is connected to a needle by means of a fine silk cord so that the needle points to the number on the scale corresponding to the airplane speed. The needle is brought back to the "zero" position by means of a small, spiral spring.

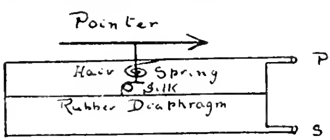


FIG. 38.

This instrument lags because a certain amount of air has to find its way into the box before the needle moves.

This gauge is not suitable for hot countries because the rubber very soon begins to rot and this alters the reading.

The second type is much the same as the one above except that the diaphragm is made of metal and it is connected to the pointer by a system of levers.

This instrument is affected by changes in temperature which make the diaphragm more or less elastic.

The third type of instrument works on the same principle as the above. It consists essentially of a small metal box similar to that which is used in aneroid barometers. This box is connected to the pressure part of the pressure head. This metal box is fixed inside the main case of the instrument, which is air-tight and connected to the suction part of the pressure head.

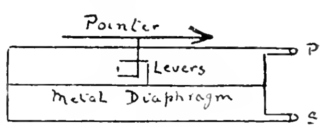


FIG. 39.

As the small metal box expands or contracts it moves the pointer of the instrument backward and forward by means of a small rack and pinion.

The use of air-speed indicators on airplanes.—As far as the pilot is concerned, it does not matter what figure the air-speed indicator in the machine registers. This figure alters with height very considerably, and is also affected by temperature. The instruments do not register small, quick changes in speed and are not useful in bomb dropping because they do not register the ground speed. Where they are exceedingly important is in night flying, flying in clouds, and when it is necessary to get the maximum climb from the machine. Every pilot, by trial, knows the speed of his airplane when flying level, so that at night he can tell with fair accuracy how his machine is flying. No pilot can tell by the feel of his machine when he is doing the quickest climb, but by reading his watch and aneroid he knows what his air-speed indicator ought to register, so that after the first trial he can simply keep his machine steady at this speed in order to insure that his machine is rising as swiftly as possible.

When the air speed indicating the quickest climb has been found this figure is correct for every height, although the correct reading of the instrument alters with the height. This is because the angle of the machine has to be increased considerably at the higher altitudes in order to get the best performance.

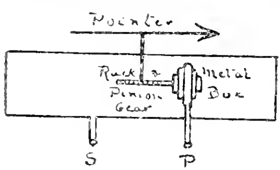


FIG. 49.

The compass—General description.—The compass is constructed on the principle of suspending a magnet (or system of magnets fixed parallel to each other and referred to as the "compass needles") in such a manner that, remaining horizontal, they are free to take up the direction in which the magnetism of the magnetic pole directs them. This direction is called the "magnetic meridian."

A circular graduated card called the "compass card" is fixed to the compass needle so that one diameter of the card, the opposite extremities of which are marked north and south, respectively, is in the same line as the direction of the needles. The point marked "north" (in land and water compasses distinguished by a fleur-de-lis or other special mark) is placed over that end of the needle which always points to the northward. The extremities of that diameter which is at right angles to the north and south line are marked east and west, east being to the right hand when the observer is facing to the northward. The compass card is thus divided into four quarters of a circle, or quadrants, and the points thus obtained are called the "cardinal points." These divisions may again be subdivided into the half and quarter cardinal points.

In the center of the compass card a small semicircular cap is fitted slightly hollowed on its underneath side. This supports the card by resting on a sharp-pointed pivot made of very hard metal. Thus the card is suspended on an almost frictionless point and is free to maintain its direction when the airplane is turned.

The pivot itself is fixed to the center of a bowl called the "compass bowl." This bowl is covered by a glass plate or a hole is cut in it to which the glass plate is fixed.

All airplane compasses are of the liquid type; that is, the bowl is filled with water and spirits. This takes the weight of the card off the pivot, so that the compass becomes very sensitive. It also makes

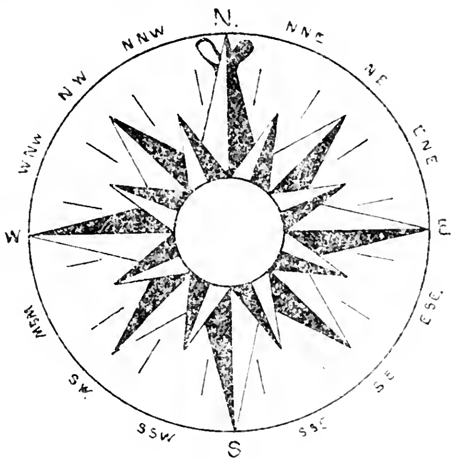


FIG. 41.

the needle come to rest quickly, so that it very soon points to the north after a turn has been made.

On the bowl of the compass will be found a mark called the "lubber's point," and when mounting a compass in an airplane this point should be in the fore-and-aft line of the airplane and pointing directly ahead. Thus it follows that the "lubber's point" moves with every turning movement of the airplane, and to ascertain the direction of the airplane's head the observer has only to notice what point on the compass card corresponds with the "lubber's point." This bearing is called the "compass course," or direction in which the airplane is being steered. The "compass course" may also, as an alternative, be described as the angle made by the point of the compass coinciding with the "lubber's point" and the north point.

Airplane compasses are usually marked at the half cardinal points and the card is graduated in degrees reading from north to 360 clockwise, i. e., east will be 90°, south 180°, and west 270°. As the cards are very small, it is usual only to mark every 20°, and the last figure "0" is left out for ease in reading. It is very hard, indeed, to steer an airplane within 5° of the required course, so that the graduations are not abnormally large.

There is another way of designating compass bearings, but it is not used in the land services. This method is to describe a bearing as so many degrees east or west of north or south; that is, southwest would be described as S. 45° W., etc.

Errors to which compasses are subject.—The compass is unfortunately affected by errors. The ones chiefly concerning aviation are—

A. Variation.

B. Deviation.

C. Dip.

D. Air bubbles in liquid.

Table of compass bearings.

Bearing.	Degrees.	Bearing.	Degrees.	Bearing.	Degrees.	Bearing.	Degrees.
N.........	0	E.........	90	S.........	180	W.........	270
N. by E..	$11\frac{1}{4}$	E. by S...	$101\frac{1}{4}$	S. by W...	$191\frac{1}{4}$	W. by N..	$281\frac{1}{4}$
N.-NE....	$22\frac{1}{2}$	E.-SE....	$112\frac{1}{2}$	S.-SW....	$202\frac{1}{2}$	W.-NW...	$292\frac{1}{2}$
NE. by N..	$33\frac{3}{4}$	SE. by E..	$123\frac{3}{4}$	SW. by S..	$213\frac{3}{4}$	NW. by W.	$303\frac{3}{4}$
NE......	45	SE........	135	SW.......	225	NW.......	315
NE. by E..	$56\frac{1}{4}$	SE. by S..	$146\frac{1}{4}$	SW. by W.	$236\frac{1}{4}$	NW. by **N.**	$326\frac{1}{4}$
E.-NE.....	$67\frac{1}{2}$	S.-SE.....	$157\frac{1}{2}$	W.-SW...	$247\frac{1}{2}$	N.-NW...	$337\frac{1}{2}$
E. by N...	$78\frac{3}{4}$	S. by E...	$168\frac{3}{4}$	W. by S...	$258\frac{3}{4}$	N. by W..	$348\frac{3}{4}$

The above are called the "points" of the compass. Each "point" is equivalent to an angle of $11\frac{1}{4}$ degrees.

A. *Variations.*—A suspended magnet or compass needle does not point to the true or geographical north but to a point known as the magnetic North Pole. The difference between this direction and the direction of the true north is called the "variation of the compass" or shortly "variation."

The variation changes according to ones position on the earth's surface and also annually; the latter is very gradual but the former must never be ignored. Variation is measured in degrees to the east and west of true north at Greenwich; at the present time the compass needle points about 15° to the west of true north at Greenwich and as one goes west it gradually increass to 30° and then decreases until about the middle of the State of Ohio there is no variation and still further west the variation changes to easterly.

The variation on the east coast of America near Washington is about 8° west and the variation in California about 14° east.

Near Greenwich the variation is decreasing by about 8″ annually.

The actual variation can be obtained from the Ordnance Survey Maps. These maps are made out on the true north and south principle so that a course taken from them would be a "true course" and the variation must be applied before a "magnetic course" is obtained.

B. *Deviation.*—This is due to the local attraction of steel and iron fittings in the immediate vicinity of the compass; it varies both in magnitude and direction for different positions of the airplane. It therefore will be readily understood that it is necessary to place a compass in an airplane in such a position as to be as far as possible free from these influences. This, however, is a difficult matter; but so long as the compass is not affected to a greater extent than about 5° the error can remain uncorrected, as for practical work it will be found difficult to steer an airplane accurately enough for this amount of error to seriously matter. If, on the other hand, the error is considerably in excess of 5° it should be the work of an expert to correct it by means of magnets placed near the compass in such a manner as to counteract the local influence on the needle. Most compasses carry an arrangement to hold the small "compensating magnets" both in the fore and aft line of the machine and also transversely. Should a pilot be of the opinion that his compass is considerably "out" on a certain course his best method is to point the airplane at a distant object situated on or near that course, start up the engine and note the reading of the card, at the same time taking a bearing of the object by means of another compass (known to be free from local error) placed in line with the airplane and object, but at some distance away. By comparing the two bearings obtained the pilot can at once ascertain the error and if unable to correct it by magnets he must remember to apply it to his "magnetic course."

This method can be employed for all directions of the airplane and a table made out showing the deviation for every 10° or 20°; but it is more satisfactory if the pilot can have his compass properly corrected when it is first fitted on the airplane so that the only error he has to apply is variation.

Every machine which has passed the inspection department carries a small plate on which are marked the actual compass readings at each of the half cardinal points.

C. *Dip.*—The earth's lines of magnetic force are not horizontal except near the Equator and they vary at every latitude until at the magnetic North Pole a compass needle free to swing up and down would point directly down toward the earth. On account of

this tendency of the needle to dip it is necessary to fix a small weight on the south end of the needle or compass card (in the Northern Hemisphere) so as to make it hang horizontal. If the needle of the compass is strongly magnetic this small weight has to be comparatively heavy.

D. *Air bubbles in liquid.*—An air bubble is a large factor in producing inaccuracy in a compass. If the bubble is sufficiently big the vibration will cause the liquid to froth and the card will become illegible. At the same time the friction caused by the bubble moving in the bowl will tend to deviate the card from the magnetic course. In some cases it will even cause the card to revolve completely around.

If it is desired to get rid of this bubble, the compass bowl should be turned on its side until the filling hole is at the top. Remove the plug and fill the bowl carefully with distilled water, or, better still, with the special compass liquid. During this operation care must be taken to insure that the passage of air out of the bowl is not hindered by the presence of drops of liquid in the plug hole. When the bowl is completely full to the top of the plug hole replace the plug.

AIRPLANE COMPASSES USUALLY MET WITH.

A. *The naval and military airplane compass.*—In this compass the bowl rests in its outer casing on a horsehair pad and is kept in place by three trunnions with rubber rings which fit into brackets on the inside of the case. The horsehair is in order to prevent the bowl vibrating too much.

The bowl is filled with a mixture of three parts distilled water to one part of alcohol. The bowl is filled through a filling plug (fitted with a brass screw) situated on one side.

The suspension of the compass card is arranged as follows:

In the center of the card there is a circular cap inside which is fixed an amethyst. This amethyst rests on a pivot fixed to the bottom of the bowl and having an iridium pointed tip. Attached to the underside of the card and $\frac{9}{32}$ inch from it there are two magnets $2\frac{3}{4}$ inches long by $\frac{3}{32}$ inch diameter. The centers of these magnets are $1\frac{3}{8}$ inches apart.

The compass card is graduated from 0° at north every 10° right handed through east 90°, south 180°, and west 270°. The final 0 of each number is omitted, so that 280° reads 28°, etc., on this card. The card is also marked in cardinal and half-cardinal points; the figures and letters in the northern quadrants are red and in the southern blue. On the outer rim of the card is marked a set of degrees inverted, which are reflected correctly in a prism fitted immediately over the "Lubbers point." The bracket for this prism

is fixed to the bowl, but the prism itself can be moved to suit the individual user and his vision relative to the compass.

The "Lubbers point" is of brass wire, in the shape of a right angle triangle, only two sides of which are seen—one when viewed directly and the other when the prism is used.

On the outer rim of the bowl is a movable circumference having a wire diameter across the top of the bowl. This wire is called the "course pointer," and can also be used to assist the reflection of the "Lubbers point," when the former is laid coincidental with it.

Let into the bottom of the bowl, immediately under the "Lubbers point" and prism, is a one-half inch diameter circle of opaque glass. Inside a holder which can be placed on the various quadrants of

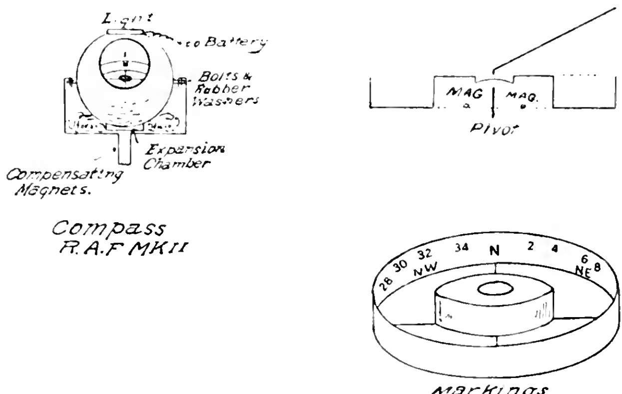


FIG. 42.

the case is a dry cell—1.3 volts, 0.3 ampere—which lights a 0.5-candlepower clear-bulb lamp fixed inside the case and under the bowl. The light from this lamp shines through the opaque glass and up into the prism. The "Lubbers point" and also the degrees on the card reflected to the prism are thus illuminated so that the compass can be used at night.

At the bottom of the bowl, covered by a light plate held in place by four nuts, is an expansion chamber. This allows for the liquid becoming heated by the lamp, or by differences in atmospheric temperature. This chamber can also be used for getting rid of any air bubble which may be in the liquid.

B. *The R. A. F., Mark II, compass.*—

This compass consists of a spherical bowl which rests in a case on a pad of horsehair and is connected to it by bolts and rubber washers.

A circular window is placed in the side of the bowl toward the top, so that the card can be seen. The bowl carries an expansion chamber at the bottom and a holder for a small electric light at the top. The outer case has a fitting to take the standard compensating magnets attached to its underneath side.

The compass card consists of a circular disk which is mounted on a pivot attached to the bottom of the bowl. This disk contains two magnets, and it is prevented from lifting off the pivot by a wire attached to the side of the bowl. Fixed into the disk are two wires at right angles which carry on their ends a ring on which the markings are borne. This ring is marked on the inside with the cardinal and half-cardinal points. It is also graduated every 20°, the last 0 of each number being omitted for the sake of clearness.

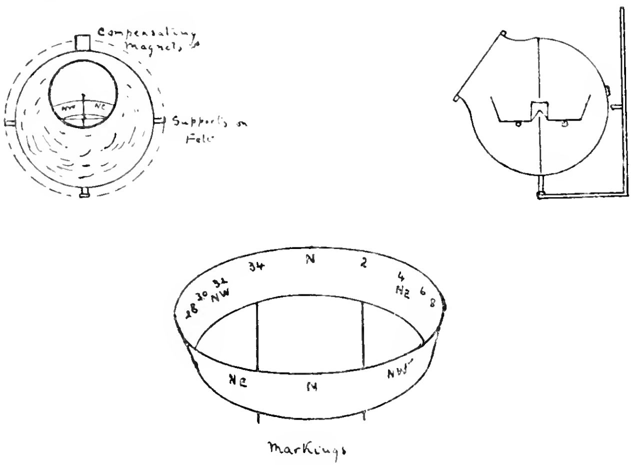


FIG. 43.

This compass has short and weak magnets so that the card has a long period of oscillation. The card of this compass is little affected when the airplane turns.

C. *The Creigh Osborne compass.*—This compass consists of a spherical bowl which has a window similar to that mentioned above. The bowl is supported in three places by lugs which rest on brackets projecting from a frame and to which they are attached by bolts and felt washers. On top of the bowl is a fitting to take the compensating magnets. This compass has no expansion chamber, and a bubble of air is purposely left inside the bowl to allow for expansion of the liquid. The card is supported in the usual manner to a pivot

fixed to the bottom of the bowl and is prevented from falling off by a wire attached to the top of the bowl. Two magnets are fixed to the underneath side of the card, and the outer edge of the card is turned up at an angle. This turned-up part carries the markings. On the inside it is graduated every 20° in the same manner as the compass mentioned above, and it also is marked with the cardinal and half-cardinal points. The outside of this turned-up part of the card is marked also with the cardinal and half-cardinal points. At the bottom of the circular window are two wires which cross at right angles; the vertical one is the "Lubbers point" and the horizontal one is to aid in keeping the airplane horizontal. This compass has long and comparatively strong magnets and has therefore a short period of oscillation.

Action of compass when flying through clouds or at night. It used to be said that clouds were "magnetic" because pilots found that the compass card would swing apparently of its own accord as soon as the machine entered the clouds. This was observed when the compass alone was used to steer by and it was not always observed. The clouds which are usually met on a flying day are not "magnetic." The electricity in the black thunder clouds may affect the compass needle but one does not usually fly in thunder storms. The explanation of the swinging of the compass card is as follows:

As has been mentioned above, the north end of the magnetic needle tends to dip in the Northern Hemisphere and the amount of the inclination depends upon the latitude. This tendency is counteracted by placing a small weight on the south end of the needle in order to make it hang level. (Fig. 44, *a*.)

Suppose a machine was flying north and is turned, either because the pilot wants to turn or because he does not know that he is turning. As soon as the machine leaves its course centrifugal force acts on the compass needle and the card being hung from the point of the pivot will wing outward and take up the angle corresponding to the turn. As the card is supported at one point only it will tend to take up its proper angle no matter if the machine is making a turn with the proper bank or if it is skidding round.

If the turn is made to the left (west) one would imagine that the card would swing out and that the needle would still point to the north and that the "Lubbers point" would move to the left, thus showing a turn to the left. (Fig. 44, *b*.) In most compasses it does not do this and this is what actually happens. The card swings outward, but the south end being heavier than the north will swing with greater vigor, so that the north end of the card is swung inward and the "Lubbers point," instead of moving to the left, moves relatively to the right and registers apparently a right-hand turn.

If one were steering by compass alone the pilot would put on the "left rudder" and the error would be increased. Very soon the pilot would have lost all sense of direction and the card might swing completely round, as it often does. If the pilot has any point to steer on the swinging is put down to the ordinary lag of the compass and the pilot holds the machine steady until the card has settled.

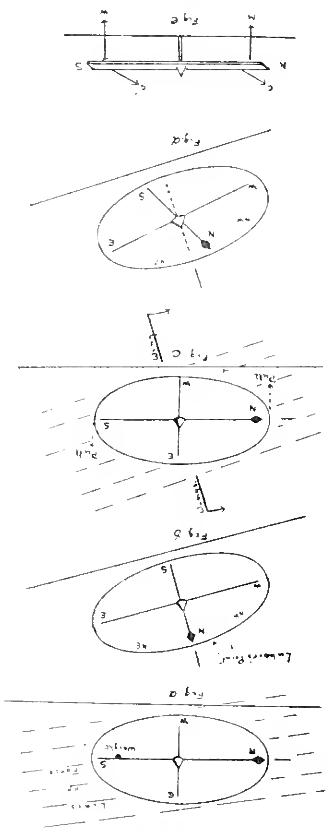


FIG. 44.

It might be thought that this error could be adjusted by altering the weights of the compass card, but this can not be done. Consider the forces acting on the needle from another point of view. As soon as the card tilts the resultant forces affecting the needle (all except magnetic attraction) act in a plane at right angles to the plane of the compass card (which is not horizontal). The magnetic force always tends to pull the needle so as to make it lie parallel to the earth's lines of magnetic force, and this means that there is always an unbalanced force tending to pull the north end of the compass needle vertically toward the earth; i. e., toward the inside of the turn and not outward as one might expect. The only way of correcting for this error is to make the magnets weak so that there is very little magnetic force and therefore very small extra weight on the south end of the needle acting unbalanced in a turn.

When flying south the heavy end of the needle will still tend to fly outward on a turn, but in this case the error will be in the proper way; that is, if the machine turns toward the west the error will also be toward the west and the pilot can easily see which way to put the rudder.

Pilots should examine their compasses and find out if they are of the type which will tend to turn the wrong way or the right way

when the machine is turning north. Those compasses with a short period are likely to be wrong; those with the long period will probably be right.

If the compass is of the wrong type and it is found necessary to fly through clouds, the machine should be pointed south until it is clear of the clouds. As the compass card takes a certain time to settle down after a turn any turning necessary should be completed at least one minute before the machine reaches the cloud.

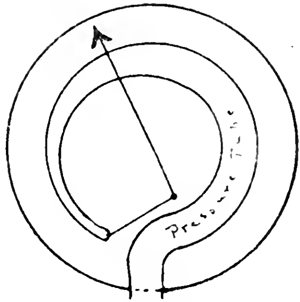


Fig. 45.

AIR-PRESSURE GAUGE.

Air-pressure gauges usually consist of a flat tube of thin metal bent round in the form of a circle, one end is connected by a pipe to the tank, the other end is closed and attached by means of a small link to the end of a pointer. The principle of the gauge is this: When a bent tube is acted on by pressure from the inside it tends to straighten. The scale of the instrument can easily be graduated with reference to a standard pressure gauge.

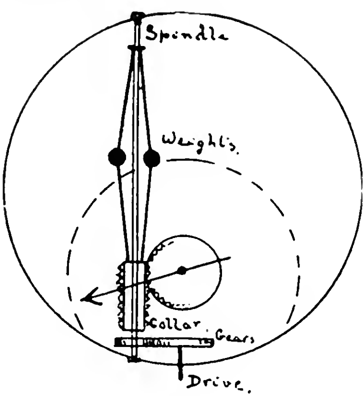


Fig. 46.

Revolution indicators.—The most usual form of revolution indicator for the engine consists essentially of two weights which when rotated fly outwards, the amount corresponding to the speed of the engine.

The weights of the indicator, two or three in number, are attached to the middle of springs, one end of the springs are attached to the end of a vertical spindle, the other ends are attached to a collar which is free to move up and down the spindle. This spindle is rotated by means of a flexible drive by some suitable part on the engine such as the pump spindle. If necessary a gear box is attached between the drive and the indicator so that the indicator will show suitable readings. The movable collar on the spindle is grooved

and these grooves fit into the teeth of an arc carried on the axis of the pointer so that when the weights swing outward the collar is drawn up the spindle and this rotates the arc and therefore the pointer. The pointer thus points to the number of revolutions corresponding to the amount the weights have swung outward. As the speed of the engine lessens the weights are drawn in toward the spindle by means of the springs to which they are attached. Small lubricating cups are carried at each end of the spindle and these should be oiled from time to time. The flexible drive should not be led round sharp corners and it should not be fixed in small curves, otherwise it will be broken and this especially applies to the end where it is attached to the indicator or the engine.

Levels.—All machines carry a level to show if the machine is flying one wing high and some machines also carry a fore-and-aft level. These are usually of the ordinary liquid type; the tube is slightly curved so that the bubble shows on the top of the curve. These levels are only correct when the machine is flying on a steady course. If the machine makes a turn with the proper bank the bubble will stay in the center and register no inclination of the wings. If the turn is too flat the liquid will be pulled outward by centrifugal force and the bubble will show toward the inside of the curve and this gives apparently a wrong reading. If the machine is banked up too much for the turn the bubble will show on the outside of the curve. The airplane should be flown therefore so that the bubble of the transverse level is always in the center. In the same manner the fore-and-aft level will only register correctly when the machine is flying in a straight line and will not be correct when the machine is changing to a climb or glide.

INSTRUMENTS FOR SHOWING MAXIMUM CLIMB.

There is a simple instrument for showing when the machine is doing its best climb and it consists essentially of the following: A vacuum flask, something similar to that of the thermos bottle, has two tubes leading out of it. The first tube is almost closed, only a small hole being left. The other tube is connected to a U tube containing a liquid. When the machine climbs the pressure of the air inside the bottle becomes greater than the air outside. The air inside therefore expands, pushing the liquid up one branch of the U tube, at the same time the air excapes through the small hole in the first tube. When the machine is doing its best climb the difference of pressure between the air inside the bottle and the air outside becomes a maximum and the liquid is pushed as high as it

can be up the branch of the U tube. The machine should therefore be climbed with the liquid as high as possible in the U tube. When this is being done the reading on the air-speed indicator should be taken and noted for future use. The bottle is of the vacuum

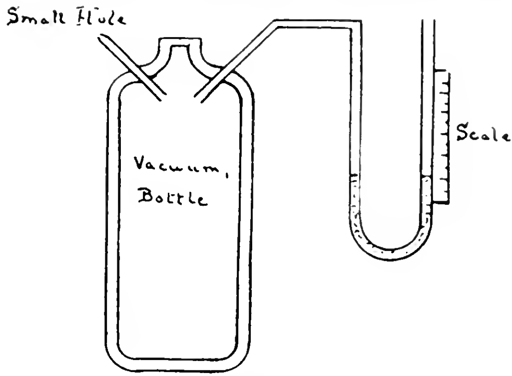


Fig. 47.

type so as to prevent the difference in temperature of the air outside affecting the air inside the bottle.

INSTRUMENT FOR TELLING WHEN THE MACHINE IS FLYING LEVEL.

There is a simple instrument for telling when the machine is flying level, which depends on the following principle: A vacuum

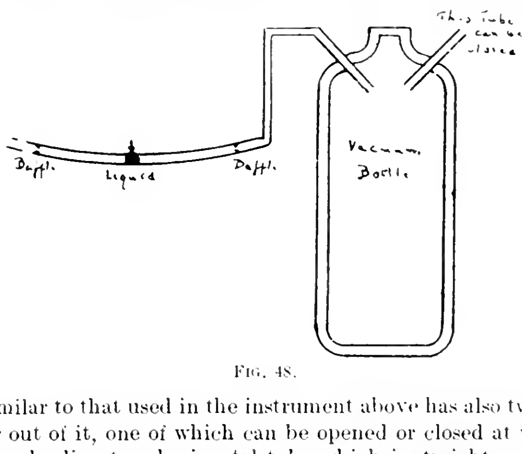


Fig. 48.

flask similar to that used in the instrument above has also two tubes leading out of it, one of which can be opened or closed at will and the other leading to a horizontal tube which is straight or may be slightly bent. In the middle of this horizontal tube is a drop of

colored liquid. This drop clings to the sides of the tube and if there is any difference of pressure between the air outside the bottle and that inside the bottle it will move back and forth in the tube. If the first tube is closed and if the machine is flying level the little drop of liquid will be in the center of the tube and will not move- Directly the machine starts to go up or down there will be an immediate change of pressure between the air outside the bottle and that inside so that the drop of liquid will move one way or the other. There is a small baffle at each end of the tube to prevent the liquid being sucked into the bottle or being blown out altogether. When the first tube is opened, if the horizontal tube is slightly bent, the liquid will return to the center of its run. This instrument can be made with a diaphram and with a suitable gearing between the diaphram and a pointer to magnify the movements of the diaphram.

XIII. NAVIGATION OF THE AIR.

General remarks.—Accurate navigation is obtained by intelligent use of a compass combined with a good knowledge of topography to assist in rapidly locating the position.

The greatest difficulty is experienced by pilots in finding their way across country at the first attempt even if the locality is well known from below. The country presents a different aspect when viewed from above, and only by constant practice can a pilot become what is known as a "good cross-country flyer."

The secret of success in navigating an airplane is careful attention to details. The pilot's task is made considerable easier if he has a trained observer as passenger, with suitable means of communicating with the latter.

Maps.—Pilots must be well acquainted with map reading; not only must the pilot be able to check the turnings and the different objects as is done when using a map on the ground, but he should have the whole of the country in his mind. It should not be necessary to turn the map upside down or sideways so as to get one's course always from the bottom to the top of the map. A little training will enable the pilot to read the map at once if he places it in his case with the north toward the top so that the names of towns, etc., can easily be read. Maps should be neatly folded and placed in the map case. They may be marked with a soft lead pencil so that the marking can easily be rubbed out, but it is a mistake to use ink on any map or to pin it to a board, for this destroys the map and allows it to become dirty and torn and even sometimes to be blown away altogether.

For ordinary flights the most useful scale is about 3 miles to the inch (R. F. 1/200,000). A map constructed to this scale can be

folded so as to take in the whole area of the ordinary reconnaissance. For long flights the map will have to be cut into strips and mounted on rollers. When this is done it is convenient to cut the map so that one's course shows along the middle of the map. It requires a little practice to read the maps when this is done.

For artillery work and special duties it is necessary to use a map of a much larger scale. A convenient size is about 3 inches to 1 mile (R. F. 1/20,000). These maps show the country in great detail. They are usually divided up into squares which are numbered on a certain system. These maps can conveniently be cut into squares and mounted on thin boards and then varnished. A suitable case should be provided in the machine to take these maps so that they will not become damaged or blow away when they are not in use.

It is often necessary especially in a war to use foreign maps, the scale of which is usually given as a representative fraction. Pilots when supplied with these maps should immediately construct the corresponding scale with which they are familiar. This will facilitate rapid calculation of distances in units with which pilots are accustomed to work.

The pilot having been directed to proceed to a number o points or some certain point must study his map very closely before he gets into the machine in order to ascertain what guides he can best use to assist his navigation. If there is no side wind and his compass is correct, a straight course from point to point is the quickest. The points on the map should be joined by a line and the "true course" measured. To this the variation of the compass in that locality must be applied, and he then has the compass or magnetic course to be steered. If the variation of the compass is west the variation must be added to the true bearing in order to get the proper magnetic bearing. If the variation is east the variation must be subtracted to get the compass bearing. This compass bearing should be written down and kept in some conspicuous position in front of the pilot. The distances from the starting point can also with advantage be marked either at 10-mile intervals or from some well-defined object passed en route to the next. Sometimes it is advantageous to mark these intervals in time, say every 10 minutes, so that the pilot may know at what o'clock he should be over certain places. It should be noted whether any very high ground is to be passed over necessitating a greater height being maintained at that point.

Selection of objects as guides.—The following remarks are the result of practical experience:

Towns.—Towns are obviously of the greatest assistance. In case of doubt they are usually most easily identified by the railways.

No airplane should pass directly over a town as not only is such a practice contrary to law, but also unless flying at over 2,000 feet the effects of any large works with blast furnaces will be felt. On hazy days it should be remembered that smoke hangs over villages and sometimes gives them the appearance of a large town from some little distance away.

Railways.—Railways are of very great assistance and can be used to a large extent as a guide from point to point.

The conventional sign for a railway is a plain black line on the map, and no distinction is made between a line with perhaps four pairs of rails and one pair of rails. Thus it is quite easy to make a mistake if a single line branches off from the main line in perhaps a not too conspicuous place. Branch lines to quarries are often not marked on the map even though they may run a mile or more away from the main line. Tunnels, bridges, and cuttings are marked on maps and these will often be of assistance in picking up the correct line

Sometimes grass is allowed to grow over the track especially if it is a light railway and this makes it practically invisible from a height of 3,000 feet. In snow a tarred road which has had a little traffic over it looks very like what a railway does in the ordinary times and it is very easy to make a mistake.

In spite of the above few details which are liable to cause an error, a pilot may find it worth his while to keep to the railways and go a little farther round and this applies especially in misty or windy weather, when it is hard to keep to a compass course. In this case the general direction of the railway should be noted so that the pilot will not find himself following the wrong line.

Roads.—As a general rule roads are not a particularly good guide. Many roads twist about considerably. Main roads are often less noticeable from a height than minor roads. The telegraph wires and poles (a sure sign of an important road) are also very hard to see. In the neighborhood of the fighting line the places where troops have marched during the night, even if they have gone across country, look very like a permanent road, especially of the soil is chalky.

There are exceptions to the general rule. Roman roads being usually absolutely straight can generally be picked out easily and also roads over a moor or plain where there are few others in the vicinity with which to confuse them. The Napoleonic roads in Europe, which are planted on both sides with poplars and which are straight for miles, make very good landmarks.

Water.—Water can be seen from a great distance and is the best guide. After much rain a pilot must take into consideration the possibilities of a flooded stream causing the surrounding meadows,

etc., to be inundated to a depth of perhaps only a few inches, but nevertheless having an appearance of a good-sized lake or broad river which can not be located on the map.

Rivers are very winding and are often almost concealed by high trees on either bank. A pilot will usually waste time if he elects to follow a river as a means of getting from point to point. On most maps the smallest rivers are marked very distinctly which will at first encourage a pilot to follow them.

Large canals are easy to see and often go very straight. In dry weather the course of a river can be noticed at once by the difference in color between the trees near the river and those farther away.

Woods.—Woods can be seen from a distance and can often be identified very easily by their shape or the shape of cuttings, but it should be borne in mind that it is very easy to alter the shape of the woods or even to cut it down altogether so that the location can not be seen when flying at a little height.

High ground.—From a height of 2,000 feet and over country presents quite a flat appearance and contour can not be recognized. In early morning or late evening hills may cast a shadow and stand out from the surrounding country. A pilot should not fail to note any high ground with steep contours which will make landing difficult and he should fly high at these points. The general lay of the country should be borne in mind. In many places the edges of the plain or downs are very distinct and may form a convenient mark. On a long cross-country flight the color of the country will change on account of the differences in trees or grass and this may aid the pilot in case of doubt.

Forced landings.—Landing ground is hard to recognize as being good from a greater height than 1,000 feet. The nicest height at which to fly is about 3,000 feet. At this height the ground can be clearly seen, the machine is usually above the "bumpy" air, and in case of engine failure can glide for some little distance before the spot for landing on need be finally selected.

The best time of year for flying is undoubtedly the autumn, when the crops are in. At this time a pilot should choose for preference a stubble field which from a height presents a lightish brown appearance. By doing this he can be quite certain that the surface will be smooth without ditches or mounds, whereas the ordinary grass field as often as not abounds in the latter. Dark green fields are usually found to be roots and as such should be avoided if better ground is available. In the winter rain may make the stubble and root fields very soft and may make the machine turn onto its nose on landing. When they are like this it is very difficult to make the machine rise off the ground. Grazing land may be identified by the feeding

cattle. Should a pilot land in growing wheat he should land with the tail well down as though the top of the grain were the ground. The machine will then "pancake" the last foot or so and unless it is a very light scout will land without damage and without turning over. When a machine lands in crops it should be pulled to one side as soon as possible so as to prevent more damage to the crops than is absolutely necessary.

Wind.—Navigation would be comparatively easy if wind did not enter into the question. It is the more difficult to allow for as it varies both in strength and direction at various heights. On the other hand an intelligent use of the strength and direction of the wind may greatly aid the flight, by traveling high up or low down as is most suitable.

A side wind will cause an airplane to drift—that is to say, it will have to head up into the wind a greater or less extent in order to remain actually traveling along the course required. (Note that this drift has nothing to do with the "drift" of an aerofoil.)

Should such a side wind be blowing when a pilot is about to start on a flight to a point some distance away, it will be quite worth his while to make a small diagram calculation on his map to ascertain how much he should allow for it.

This can be done in the following manner:

A is the point of departure.

B is the point of destination.

Join A B; this will represent the required course.

From A (point of departure) draw a line down wind (i. e., with a southwest wind the line would be northeast from A). Find out the speed of the wind from the meteorological map or telegram (suppose it is 20 miles an hour).

Suppose the speed of the airplane is 60 miles an hour.

Lay off along the wind line from A two units of measurement; AC will then represent 20 miles an hour. Lay off along AB a distance six units in length. AD will then represent 60 miles an hour. Join CD and draw a line AB′ parallel to CD and equal to it in length.

The compass course to be steered will be AB′, and this bearing can be measured from the north in the usual manner. Remember to allow for variation of the compass. The airplane although pointing in a direction parallel to AB′ will travel over the ground along the line AB, and the distance AD measured in the same unit of distance will represent the speed of the airplane relative to the ground.

For the return journey a fresh diagram must be made. It is not sufficient to simply add or subtract the error BAB′ from the course BA if it were subtracted or added in the first instance. The machine

will be in the air a different length of time and this will cause a different angle of error.

A practical way of finding the course is to pass over two points on the aerodrome which are known to be in the same bearing as that of the distant point. By trial make the machine fly over these two points when flown on a constant bearing. Note this bearing. If the machine continues to fly on this bearing it will reach the distant point.

Always when flying in a wind select a point some distance ahead over which one ought to pass. This will relieve one of the necessity of continually looking at the compass because the compass need not be checked till one has reached the selected point when another point on the required bearing should be selected.

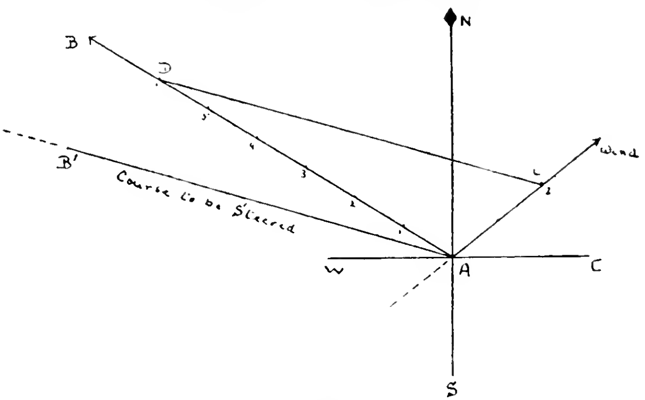


FIG. 49.

Time.—In an airplane it is most difficult to estimate time. On calm days it seems to pass quickly, but on a rough journey the minutes pass very slowly. Thus it often happens that a pilot who has not checked the time of passing some object expects to pass the next long before it is really due. On a reconnaissance the time should always be kept in mind so that one will have sufficient gasoline in order to bring one home.

Instruments.—The following instruments should be fitted in an airplane intended for cross-country work:

A properly adjusted compass.

A watch, fixed to the airplane by some suitable mounting which prevents excessive vibration.

An aneroid with adjustable height reading.

An engine revolution indicator. However skilled a pilot may be in detecting faulty running of his engine, after a long flight his

hearing will not be so good and an indicator will assist him considerably. When flying over the enemies' lines it prevents a certain amount of mental worry wondering if one's engine is rotating properly.

An air-speed indicator. This should always be carried and is especially necessary when a machine has to fly at night or through clouds. The indicator will show changes in the airplane speed so that the pilot can tell when he is climbing or going down. On a long flight one becomes tired and can not tell how one is flying without the aid of an instrument.

An inclinometer is required for ascertaining the angle of flight when the earth is not visible. For longitudinal angles the air-speed indicator is usually sufficient, as by noticing whether the speed is increasing or decreasing the pilot knows whether he is going down or up.

A map case should be provided where it can easily be seen so that the map may be visible and run no risk of loss or damage.

Lights: All the instruments should be suitably lighted in case the machine has to be out after dark. This is conveniently done by means of small electric bulbs and dry cells.

Gasoline gauge: It is useful to have a gasoline gauge so that the amount left in the tank can be checked at once.

An observer should carry the following instruments:

A watch fixed to the outside of the flying jacket around the arm or leg.

A compass, carried in a similar manner.

An aneroid is interesting, but not as a rule absolutely necessary.

Maps, suitable for the job on hand which should always be carried in a map case or stuck to a board and varnished in order to prevent them becoming damaged.

Message forms and message bags.

Report forms (these are mounted on cardboard in triplicate with carbon paper between each sheet).

Pad and pencils for making notes that may be necessary.

RULES OF THE AIR.

1. Take off and land *directly into the wind*. Not only does this prevent the machine from turning over, but it also does away with the risk of collision. The only exception should be emergency landings.

2. Before starting see that the section of the field you are going to use in making your get-away is clear and that no machines are landing or gliding into this section of the field. Locate position of all machines in the air. If other machines precede you in starting, allow them to gain a distance of at least half a mile before following,

Do not follow directly in rear so that the propeller wash will be avoided.

3. Machines with dead motors have right of way over all others.

4. Machines gliding into field have right of way over those about to leave. Machines landing are often going at a greater speed than those leaving, so be careful not to misjudge the start and be overtaken by another machine.

5. Before beginning a glide see that no machines are underneath you. Those flying beneath you have the right of way.

6. In flight before making a turn see that no machines are dangerously near on your flanks.

7. Unless there is some urgent reason, never fly out of gliding distance from a possible landing ground.

8. *Aircraft meeting each other.* Two aircraft meeting each other end on and thereby running the risk of collision must always steer out to the right. They should in addition to this pass at a distance of at least 100 yards.

9. *Aircraft overtaking each other.*—Any aircraft overtaking another aircraft is responsible for keeping clear and must not approach within 100 yards (right or left, above or below) of the overtaken aircraft. An aircraft is said to be overtaking until it has drawn clear ahead of the overtaken aircraft. When one of the aircraft is an airship the distance of 100 yards should be increased to 600 yards.

10. *Aircraft approaching each other in a cross direction.*—When any aircraft are approaching each other in cross directions, then the aircraft that sees another aircraft on its right hand, forward quadrant—from 0° (i. e., straight ahead) to 90° on the right hand—must give way, and the other aircraft must keep on its course until both are clear.

11. Aircraft flying over an airdrome are bound by the local rules of the airdrome and an aircraft landing on an airdrome with which it is unfamiliar must keep clear of other machines.

12. Night flying machines should carry a green light on the right-hand wing tip and a red light on the left-hand wing tip.

RULES OF THE ROAD—AIDS TO MEMORY.

If on your right hand red appear,
It is your duty to keep clear;
For he has got the right of way;
"Look out right front," your rule by day.

But if to left of you is seen
An aviator's light of green,
There's not so much for you to do;
For green to left keeps clear of you.

XIV. NOTES ON FLYING.

GENERAL INSTRUCTIONS FOR PILOTS.

1. Before leaving the ground examine the machine carefully yourself and then get reports from both the section chiefs.

2. Always start against the wind and, if possible, in a line clear of obstacles.

3. Leave with plenty of speed. Take a normal climb. Do not climb your machine to the limit.

4. In case the engine stops before the machine has reached a height of 600 feet, land straight ahead, even if the landing is bad. Never try and turn down, wind so as to get back again onto the airdrome. This nearly always causes a fatal accident, even with experienced pilots.

5. In flying level do not run the motor full out more than is absolutely necessary; always throttle the engine, but not so much that the machine is in danger of losing flying speed.

6. Land into the wind.

7. Land with minimum speed. Touch tail and wheels together, if possible.

8. Always taxi slowly, and if there is any appreciable wind let a mechanic hold each wing tip so as to prevent the risk of the machine turning onto one or the other wing tip.

9. Never leave a machine tail to wind. When a machine is not being used, place it facing the wind and tie the controls to prevent them moving about in the gusts. The controls should be tied in such a manner that it is impossible for the pilot to sit down without loosening them.

10. Always use safety belt. It is much safer to stick to the machine, even if a bad "crash" is foreseen.

11. In the air certain machines have the "right of way," but this does not relieve a pilot from the necessity of keeping a good lookout and from the responsibility of a collision.

12. Unless it is absolutely necessary a pilot should not start his engine without assistance.

13. The pilot is responsible that the switch is in the "off" position when the propeller is being turned by hand.

14. When starting do not try to force the machine off the ground.

15. Do not make quick turns down, wind when close to the ground.

16. Remember that in a quick turn the rudder puts the nose of the machine up or down, so that if it is found that the machine is diving put on less rudder and pull back the elevator in order to complete the turn.

17. To recover from a "spiral dive" or "tail spin" put all controls in a neutral position. The elevator control may then be pushed forward gently. This converts the spin into a "nose dive," out of which the machine can easily be pulled. The spin is due to loss of flying speed, so that the essential thing to do is to, first of all, "gain speed." The use of the rudder or ailerons in a case like this merely increases the drift and prevents the machine from gathering speed.

18. Do not work the controls roughly, and this especially applies to the elevator controls when the machine is diving at a speed.

19. Do not stand directly in the plane of a moving propeller.

20. Tie all loose articles into a machine so that they can not fall out, even if it is necessary to loop the machine.

21. When coming to a new airdrome or before landing on an unknown ground always fly around once or twice at a few hundred feet and make certain of picking out a good bit of ground for landing on.

22. When landing in a restricted area do not dive the machine in order to lose height; do proper S turns and land slowly.

23. Insure that all the drift is off the machine before landing. Land with rudder neutral.

24. In case the engine fails when flying against the wind it is probably better to make for a landing ground down wind rather than try to get into a field up wind with no height to spare. It is always easy to kill height by making a spiral or S turn.

25. When gliding, throttle down the engine as much as possible and glide at the proper angle. There is one angle, usually about one in seven, which gives the machine its best and longest glide.

26. There are four types of bad landings which it is easy to make. The first is a "Pancake" which results from allowing the machine to get into the rising position when landing. In this case there will be a perpendicular bounce and on the second bounce the landing gear may break. To prevent this, open up the engine, put the machine in a flying position, and then throttle down again and land. The second type is the "Pancake" which results from bringing the machine out of the gliding position at a point too far above the ground, when the machine will drop, due to lack of speed, and may break the running gear. The third type of bad landing results from failure to bring the machine out of the glide at all, so that it touches the ground before it is straightened up. This is the most dangerous kind of bad landing. To rectify it, open up the engine after the first bounce and put the machine in the flying position, then throttle down again and land. The fourth kind of bad landing is to land

with drift. If, at the last moment, the rudder is put over the machine will swerve and the side strain on the landing gear may pull off the tires of the wheels or buckle them so that the machine may fall on one wing tip or turn onto its nose.

27. Always test the controls of the machine before leaving the ground.

28. If you become lost, do not fly about aimlessly. Either land and ask your way or else make for some well-defined landmark which you know or can easily recognize.

29. If one has damaged the machine when landing away from an airdrome, communicate with headquarters and describe exactly what one requires to make the machine serviceable, if possible calling each part by its correct name. Do not use the word "complete," such as "landing gear complete," but describe what you want as "wheels, axle, etc. (as required)."

30. When communicating your position to headquarters, describe your location exactly. Give the number of the map you are using and give your nearest large town or some such mark, so that your location can easily be found. Also give your address and telephone number.

Cross-country flying.—Before starting on a cross-country flight be sure that the tanks are full of gasoline and oil. When taking over a new machine find out what is the consumption of the engine and where the filling plugs are. While flying do not let the gasoline get below 4 gallons, so that in case the first choice of a landing ground is bad you can go up again and choose another. When flying against a head wind do not try to make the airdrome at nightfall, if there is any doubt about reaching it. It is much better to land while it is light and tie down the machine, rather than risk a landing in the darkness.

Unless one is flying over the lines one should carry a small tool kit for minor repairs.

Care of an airplane in the open.—In case a machine has to be left in the open, steps must be taken to prevent it blowing away and becoming damaged by rain and dew. Directly the machine lands it should be placed under the lee of a house or fence. The pilot should take into consideration the probable change in the direction of the wind. If the wind is likely to blow strongly, the machine should not be left too near large trees, because the branches are liable to be blown off, and falling on the machine will damage it. The controls of the machine should be tied to prevent them flapping about in the wind. The elevator control should be lashed back, so that the wind will tend to keep the tail on the ground. The

machine, of course, should face the wind. Do not turn the machine tail to wind, because it is not designed to meet the wind in this manner. If the wind is likely to blow strongly, lift the tail by placing boxes or trestles under the taliskid. This will give the main planes a negative angle and the machine will tend to stay on the ground rather than to be blown away. The wheels of the machine should be scotched up to the rear, or small ditches may be dug in which to sink them. The landing gear should be fastened to a holdfast in front and the wings and tail should be lashed down to pickets in the ground. All modern machines have small rings on the underside of the main planes for this purpose. The tail may be fixed by fastening the rope to the tail skid. The propeller, engine, and all openings in the fuselage should be covered by waterproof covers, but if these are not available old sacks make quite a good protection. The most suitable form of picket to use is the iron screw picket, such as is used with many kinds of tents; an ordinary piece of wood hammered into the ground is liable to draw, especially if the ground is wet and soft. Do not leave a machine without a guard. When a machine has been left out all night, it sometimes happens that water collects inside the planes, the rudder, etc. If this is so, let it out by pricking small holes in the underneath of the planes. Most machines now have small eyelets in all trailing edges to prevent this. In case the field is a difficult one to get out of, bear in mind that in the early morning the machine will not lift as well as it ought to until it becomes dry. A machine should always be left in the shade, because the sun's rays damage a machine more than wind and rain.

When machines are left out in the damp, the magneto is liable to get damp inside and will refuse to work in the morning. To prevent this, wrap the magneto up in waste. This is a very frequent cause of delay in starting in the mornings.

Choice of airdromes.—Landing grounds may be permanent or temporary. A temporary ground need only be good for the time of the year for which it is intended to use it, but when choosing a permanent ground the surface of the soil and its condition in rainy weather or winter should be taken into consideration.

The following are a guide in the selection of landing ground:

A. When there is a choice between two landing grounds, the one in the more open country should be selected.

B. Roads sufficiently good for heavy motor transport should lead to the ground. A side road leading to it unused by ordinary traffic is also of great use if transport can be parked on it.

C. A permanent landing ground should be at least 500 yards by 300 yards in size. A temporary ground for a few airplanes only

may be as small as 200 yards by 200 yards if the approaches are open. If trees or telegraph lines border the ground a minimum of 300 yards to clear the obstacle is necessary. This distance must be increased if the trees exceed 50 feet in height.

D. A good shape for a landing ground is an L, when the minimum length of the arm should not be less than 500 yards and the breadth 300 yards. An L-shaped ground is particularly useful if protection against weather is naturally provided by the position of trees or houses, as in diagram.

T-shaped landing grounds are also often to be found. The length of the arms in this case should not be less than 500 yards or the breadth less than 300 yards.

E. Landing grounds should be as level as possible. Although airplanes can rise from and land on sloping ground, the wind will often make such landings difficult. An airplane rises and lands up wind. It is easy therefore to rise when going downhill, but difficult to land under the same conditions. Similarly it is easy to land uphill but difficult to rise.

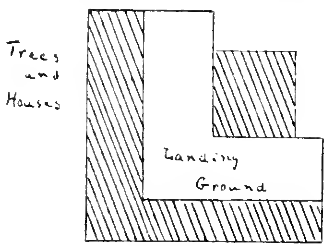


FIG. 50.

F. The surface of the ground should be firm and level. The best surface is short grass or stubble. If the surface is rough or in ridges the landing gear is apt to break on landing. If the surface is soft the airplane may tip up and break the propeller, or it may be impossible to rise at all. Plow and ridge and furrow are unsuitable.

G. Landing grounds at the bottom of hollows should be avoided if possible, as they frequently become water-logged in wet weather.

H. Landing grounds with telegraph posts and wires on their boundaries should be avoided.

Improvements.—In the field ideal landing grounds are few and far between, but much can be done to improve them. This is one of the duties of the Corps of Engineers. Landing grounds may be improved by—

A. Rolling soft or rough ground. Steam rollers are best for rough and hard surfaces, but a large stone or iron roller weighted with pieces of timber is suitable for soft ground. If it has been necessary to select soft ground and no rollers are available a good deal may be done by a body of men, such as a company of Infantry, trampling down the ground.

B. Rolling and trampling dry plow which is not ridge and furrow.

C. Filling up and rolling drains and ditches running across the ground.

D. Cutting down trees and high hedges when the space for landing is less than 300 yards. Trees must be felled so that they fall away from the landing ground.

E. Filling up large pot holes and rolling. If there is insufficient time to do this a red or yellow flag or a square of red or yellow cloth should be placed in the center of the pot hole. Care must be taken that any filled-in ground is made firm and solid.

F. Marking any other dangerous places, such as ditches at the edge of the ground.

G. Telegraph posts and wires and wire fences or iron railings must be marked by hanging strips of cloth or blankets on them, and the Signal Service should be asked to take down any air lines which might prove dangerous to airplanes and to substitute ground lines.

All work on the landing ground should begin from the center and proceed outward in order that a space for a machine to land may be provided as quickly as possible. With well directed work very unlikely looking places can be turned into practicable landing grounds in a day.

It is sometimes advantageous to build paths for landing, radiating out from a center, and to put down ashes so that these paths will not become muddy in wet weather.

Working parties must not leave their tools lying about on the ground, and when they see a machine about to descend they must at once clear the ground.

Methods of marking a landing ground by day.—Two strips of cloth colored white and arranged in the form of a T should be laid out on the airdrome. The head of the T should face directly into the wind, thus:

This gives the direction in which a pilot is to land. It is to be understood that a machine landing in the ordinary manner so that it will stop running when it reaches the head of the T will find good landing ground. A machine should not run over the mark, but just to one side.

The position of the T must be changed with any change of the wind.

Method of marking landing ground by night.—By night landing grounds will be marked with four flares as under:

It is to be understood that a machine should touch the ground near the flares A or B and that all the ground between A and CD is good for landing and free from obstacles.

It aids the pilot if a man stands at each of the flares so that he is able to judge his height when landing.

Searchlights may be used to light up landing grounds. They should be placed near the flare A and point in the direction in which the machine will land. The light should be raised to about 10 feet.

If it is any lower than this small tufts of grass, etc., cast a shadow which looks like a large hole and this is liable to interfere with the pilot when he lands.

Any parts of the landing ground which may cause damage should be marked with red lamps.

The most suitable form of flare is a bucket with half a gallon of gasoline in it. This will burn for half an hour and is visible from 8 miles off on a clear night even when the moon is half full.

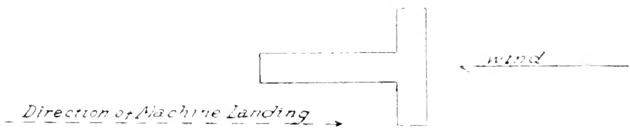


FIG. 51.

On bright moonlight nights flares and lamps may be dispensed with and the same signal used as for day.

Aviator's clothing.—The clothing for an aviator must be light and warm and should allow him to make quick movements. The essential for warmth is that the aviator should be dry when he goes up that is, he should not walk about in the wet grass and then go up into the air. The clothing should not be air-tight and should be loose.

Cap.—The cap should be of leather, lined with fur or chamois leather. It should fit tight round the face, so that when the pilot

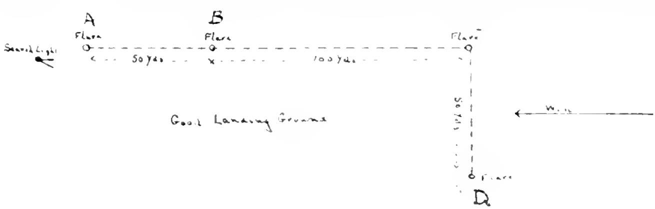


FIG. 52.

looks outside his machine the wind will not be caught by the sides of the cap. If the pilot has a comparatively large wind screen it will cause the wind to blow continually on the back of his neck, so that the cap should come far enough down so that there is no gap between the cap and the collar. Sometimes caps are made so that a mask can be strapped on for flying in cold weather. To prevent frostbite of exposed parts in cold weather, these parts should be covered with special frostbite grease which is an article of store.

Goggles.—These should fit both the aviator and the cap so that they do not leave an exposed part which would cause the aviator to get neuralgia. The glass should be either triplex, or special "unbreak-

able" glass. The triplex glass has the disadvantage that it cuts out a lot of the light and is not nice to use in the early morning or evening, or at night. It also has the disadvantage that a comparatively light blow on the outside will strip the glass from the inside and cause damage to the eyes. To get the maximum efficiency from the goggles they should be specially colored. "Novio" glass is a good type of this colored glass. This glass is expensive and hard to make, and is quite different from the cheap, colored glasses, which are as a rule worse than useless.

Gloves.—Gloves should be made of leather, lined with Jaeger wool; sometimes silk gloves are worn also underneath. There is a good type of glove which has a little bag attached into which the fingers can be slipped at the times when nothing is happening. The gloves should be loose so that they slip on and off easily and do not stop the circulation. It is an advantage to have only the thumb and first finger separate, the other three fingers in a mitten without compartments so that they will keep warm. Leather gloves should be kept clean. When they become oily they make the hands very cold. If the glove is a fur glove oil destroys the fur.

Coat and trousers or union suit.—These should be made of leather, lined with Jaeger wool or fur. If fur is used there should be some sort of inner lining to prevent the fur from being torn. Pockets in the usual places are useless. The most useful places are diagonally across the front over the chest and at the side of each knee. These pockets can be got at when the aviator is strapped into the machine. For this kind of clothing there must be some sort of wind-proof material on the outside and warm material on the inside. Leather is best for the outside material. A waterproof material on the outside causes moisture to collect on the inside, which makes the aviator very cold. There should be a wind flap over the opening of both coat and trousers.

Boots.—Boots should be made of leather and lined with fleece, or at least two pairs of thick, woolen socks can be worn inside instead. They should be loose and can be light. They should be put on just before the aviator ascends. To keep them dry while he is walking from the hangar to the machine he should wear a pair of rubber snow boots, which he kicks off as he climbs into the machine.

Instras.—In cold weather the aviator should take up something which he can put in his inner coat pockets to keep him warm. The Japanese charcoal instra is suitable for this. There is also an electric heater which can be run off a small generator, which is suitable for this purpose.

If an aviator has to start his engine himself, he should take off his coat so as not to get too hot. If he gets too hot before getting into the machine he will get very cold when he gets high up.

It is not a good thing to take alcohol before going on a high flight. The reaction, by the time one has got into the cold, is bad and makes one colder than one would be in the ordinary way.

There is a very great difference between summer and winter flying in the matter of temperature. In the winter months great care must be taken to prevent the pilot getting frostbitten. Antifreezing grease and antifreezing oil are used for the face and hands. Electrically heated union suits have so far proved the most satisfactory in the way of clothing. Electric heaters are also required for the guns. In order to mitigate stoppages and gun trouble generally, barrels and parts should be kept as dry and free from oil or grease as possible. Covers and blinds will be required for the radiators.

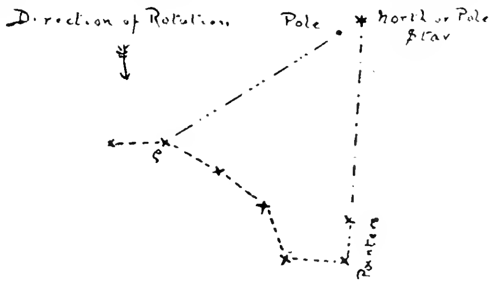


FIG. 53.

Finding the north point.—A well laid-out compass base is absolutely essential on every airdrome, and in fact every squadron should have one for its own use. The compasses on all new machines will require testing and adjusting prior to any cross-country flying. It is of the utmost importance that the compass in each machine in the squadron be tested on the compass base at regular intervals, i.e., at least once in every seven days. Should, however, anything happen to the machine that is likely to affect the compass (such as the fitting in of a new engine) the compass must be tested on the base prior to any cross-country flight. There are many occasions on which the pilot will have to depend upon the accuracy of his compass for the safety of himself and his machine. The north point can be found by night or by day as follows:

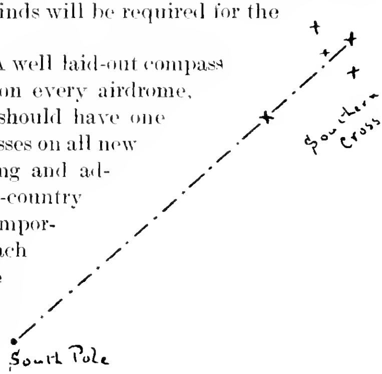


FIG. 54.

By night.—In the Northern Hemisphere it will be noticed that all the stars revolve around a single one, which is called the North Star. This star can be found easily with reference to the constellation called the Great Bear. The Great Bear consists of seven stars, arranged as shown above. One can imagine them to represent a saucepan. The handle of the saucepan points to the left when the constellation is below the North Star and to the right when it is above. The part of the saucepan opposite the handle points directly toward the North Star, and the two stars which form this are called the pointers. The North Star itself makes a small circle around the North Pole. The actual pole may be found by drawing a line from the Pole Star to the second star in the handle of the saucepan, the one called ρ. The North Pole lies on this line and 2° (as measured from the earth) away from the Pole Star. The constellation which is on the opposite of the North Star to the Great

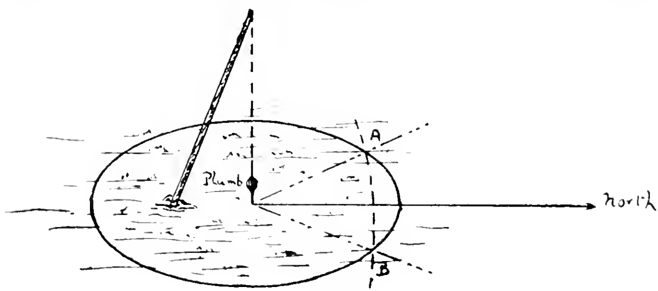


FIG. 55.

Bear is called Cassiopea. This looks like a big W and the North Star is the first bright star right above this letter.

In the Southern Hemisphere the North Star is not visible, but the South Pole may be found with reference to the Southern Cross. The Southern Cross consists of four bright stars, which can be imagined to form the ends of the cross. There is a less bright star close to one of these corners. There is another constellation not very far away, which looks something like this, but it is not nearly so symmetrical and should not be mistaken for the proper cross. In order to find the South Pole draw a line through the long arm of the cross, divide the part between the two stars into three. Then measure, away from the longer part of this arm, a distance corresponding to nine of these divisions. This point will be the South Pole.

By day. Plant a stick in the ground, pointing approximately toward the north. Tie a plumb bob to the top of the stick and allow it to touch the ground. From this point draw a circle on the

ground with any convenient radius. Note the two points where the shadow of the top of the stick touches the circle. There will be one place in the morning and one place in the afternoon. Join these two points to the center of the circle. The North Pole will be found by halving this angle.

For checking the compass it should be remembered that these points are true north. The compass points on the ground should therefore be laid out after having made the suitable correction for the variation of the compass on the airdrome.

For steering by the stars a knowledge of the constellations is not *absolutely* necessary, but it is very hard to keep a course on a single star without this knowledge.

XV. METEOROLOGY.

Introductory remarks.—Although in late years great advances have been made in the knowledge of the conditions and changes taking place in the atmosphere, yet a very large number of questions of great interest from an aeronautical standpoint still remain unanswered

Further, changes taking place in the atmosphere are very complicated, so that the problem of forecasting weather in detail is a matter of the greatest difficulty.

Fortunately the wind, which is one of the most important factors to the aviator, is the most amenable to simple, physical laws.

The composition of the atmosphere.—The atmosphere is composed of nitrogen, oxygen, carbonic acid gas, water vapor, dust, and certain other gases in small quantities. All these are mixed together and are not joined chemically. The dust in the atmosphere furnishes solid particles, around which the water vapor condenses to form fog or rain and also gives the colors of the sky and causes twilight. Over the trenches there is a considerable amount of dust caused by the exploding of shells and guns. Not only does this help clouds to form, but it affects the visibility of different points and makes it hard to take clear photographs near the lines.

The atmosphere probably extends 50 to 200 miles above the surface of the earth. That part of it which is dense enough or contains enough oxygen to support life is limited to about 30,000 feet. Machines which fly normally above 15,000 feet should carry oxygen, otherwise the hearts of the crew of the airplane are liable to be strained.

The weight of a column of air at normal temperature and at sea level is about 15 pounds per square inch, which corresponds to the weight of a column of mercury 30 inches high. The air at approximately 20,000 feet is half as dense as it is at sea level. The density of the air affects the efficiency of the airplane engine considerably.

Atmospheric pressure.—The pressure of the air—which will be seen later to be a variable quantity and its changes to be of great use in forecasting weather—is due to the weight of air above the place where the pressure is exerted. It will be readily seen that the longer the vertical column of air, and the greater the density of the air, the greater also will be the pressure exerted at the bottom of the column. Hence at two places, one above the other, the pressure at the lower place will be equal to the pressure at the upper plus the pressure due to the weight of the air between the two. This difference in pressure will not be constant, but will depend on the density of the air, which in turn varies with the temperature and pressure.

The formula connecting the difference of pressure at two places has been given under "Barometer."

The temperature of the air generally falls off with height, but near the surface of the ground the rate of decrease is often far from constant, and it is not uncommon to find a warmer layer of air above a colder one. The average rate of decrease is about 1° F. for every 300 feet. Above 5,000 or 6,000 feet the rate of decrease of temperature becomes nearly constant at 1° F. for every 300 feet. At very grea heights (over 30,000 feet) the temperature ceases to fall with height and may sometimes rise again. This region, however, is at present above the height practicable for flying.

If readings of the atmospheric pressure as measured by a barometer are taken at the same time at a number of different places situated over a wide area, and are then plotted on a map against each station the readings will be found to be arranged in some order. Certain areas will have low pressure and others will have high pressure.

On any topographical map lines or contours are drawn showing the heights of the ground equally on the pressure map it is possible to draw similar contours showing the heights of the barometer. As all places on any one contour are the same height so all places on any line on the pressure map will have the same atmospheric pressure. These lines are called "Isobars."

The isobars are generally drawn for each tenth of an inch of mercury, i. e., the difference of pressure between two places on two consecutive isobars will be one-tenth of an inch of mercury. In regions where there is a large difference of pressure between places not far apart the isobars will necessarily be close together, just as on a map, where the slope of the ground is steep the contours will be close together.

The rate at which pressure changes from place to place is known as the "Pressure gradient." When the pressure is changing rapidly the "Gradient" is said to be "steep."

On weather maps there are other lines marked in red which show lines of equal temperatures. These lines are marked for differences of 20° F. and are called "isotherms."

The wind and its connection with atmospheric pressure.—When one part of the country is under high pressure and another under low pressure, it might be supposed, at first, that air would be forced out of the region of high pressure toward that of the lower pressure, and that winds would be found everywhere blowing straight outward from the high pressures and straight inward toward the low pressures. Reference to any weather chart will, however, show that this is not what happens. The winds blow in a direction which is more nearly parallel to the isobars than at right angles to them. The explanation of this phenomenon is found in two facts:

A. The earth is revolving about its axis. This causes all winds in the Northern Hemisphere to be deflected to the right of the path

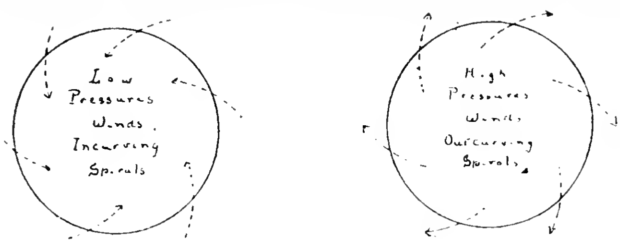


FIG. 56.

which they would follow if they were affected only by the "Pressure gradient," and tends to make them blow parallel to the isobars; similarly winds in the Southern Hemisphere are deflected to the left of this path.

B. Friction between the air and the surface of the ground tends to lessen the deflection of the winds caused by the rotation of the earth.

The result of these phenomena is that the winds at the surface blow round the centers of low pressure in incurving spirals in an anti-clockwise direction (in the Northern Hemisphere) and in outcurving spirals in a clockwise direction round the center of high pressure.

If it were possible to eliminate surface friction, the velocity of the wind could be calculated theoretically from the "Pressure gradient." An imaginary wind having this theoretical velocity and direction is called the "Gradient wind," and its velocity and direction are known as the "Gradient velocity" and the "Gradient direction."

At a height of 1,000 to 2,000 feet above the surface of the ground the effect of surface friction is very small and the actual wind has very nearly the "Gradient velocity and direction."

Table — shows the "Gradient velocity" for different values of the "Pressure gradient."

The strength of the wind is generally expressed in terms of its velocity in miles per hour. For some purposes it is more convenient to use a rougher classification and to divide all winds from calm to a hurricane into 12 groups, denoting the strength of the wind by the number of the group into which it would fall. As this system is due to Admiral Beaufort, it is known as the "Beaufort scale." The strength of the wind may also be given in terms of the pressure exerted by it, say, on a flat plate. This pressure varies as the square of the velocity.

Table — gives the relation between the velocity in miles per hour, the Beaufort number, and the pressure exerted on a flat plate in pounds per square foot.

"Gradient direction" is along the isobars with the low pressure on the left hand.

FIG. 57.

Gustiness of the wind.—It is found that the velocity of the wind does not remain constant. It is continually changing, and as a result is always rather gusty. The gustiness varies with different places and with different directions of the wind. The difference between the average maximum velocity attained in the gusts and the average minimum velocity attained in the intermediate lull is known as the "Fluctuation" of the wind.

The ratio of the "Fluctuation" to the mean velocity of the wind is called its "Gustiness," and this is found to be roughly constant for any one direction at any place, whatever may be the mean velocity of the wind.

Effect of the wind striking obstacles.—If the obstacles are low hills, such as are found on the plains and in rolling country, the wind may approximately follow the surface. If the obstacle is abrupt, such as the side of a house or a vertical cliff, the air striking the obstacle will be deflected upwards and will not touch the surface of the earth again for some distance. Thus, in the lee of a tall building there is often a calm area or the wind may be blowing in the opposite direction to the wind up above.

This is especially noticeable in places like Gibraltar when the east wind is blowing. A person standing on the edge of the cliff may be in absolutely calm air but on pushing out his arm he will feel the wind blowing vertical upward at a considerable speed. The wind blowing over the hangars on the airdrome has caused a number of accidents because pilots forget that there is a down current which is often strong enough to prevent the machine clearing the hangars.

In the old days machines which had practically no reserve of power and which could only fly level when near the ground found it very difficult to fly in windy weather. A machine on passing over a wood, for instance, might be caught in the down current on the lee side and in some cases machines had not enough power to prevent themselves hitting the ground. In the summer in sunny weather it was quite dangerous to cross a river because the down current would suck the machine practically into the water. The pilot at the present time has nothing to fear from these causes. Machines are so highly powered that they have a much greater reserve of power than they will be called upon to use when affected by the changes of velocity in the air. At the present time if the pilot does not go merely seeking danger, wind only means that the machine will take longer when flying upwind and will take a shorter time to reach a place when flying down wind. The only thing which stops war flying is low fog which prevents a pilot seeing where he has got to and will prevent him from finding his airdrome when he returns. If a pilot obeys the ordinary rules, such as getting off and landing directly into the wind, he has nothing to fear from such things that used to be called "holes in the air." "air pockets," etc., and from such things as are called cyclones, aerial cataracts, etc.

FORECASTING.

From the foregoing it has been seen that when barometric pressures are plotted on a map they are arranged according to some order. It is now necessary to consider certain typical cases of pressure distribution.

A. *The cyclone.*—

This type consists of a center of low pressure from which the pressure rises on all sides. The isobars are roughly circular about the center of low pressure. The winds blow in an anticlockwise direction round the center (clockwise in the Southern Hemisphere).

The different parts of a cyclone have each their own type of weather of which the following description may be given.

The temperature is always higher in front than in rear, the warm air in front having a peculiar close, muggy character, quite inde-

pendent of the actual height of the thermometer. The cold air in the rear on the contrary has a peculiarly exhilarating feeling, also quite independent of the thermometer.

The force of the wind depends almost entirely on the "Gradient." In the center it is dead calm and the steepest "Gradients" are usually found at some distance from center.

The relative steepness of the "Gradients" measures the intensity of cyclones.

If two lines are drawn through the center of the cyclone, one in the direction parallel to that of its motion and another at right angles to this direction, the cyclone will be divided into four quadrants, each of which has its peculiar type of weather. The line at

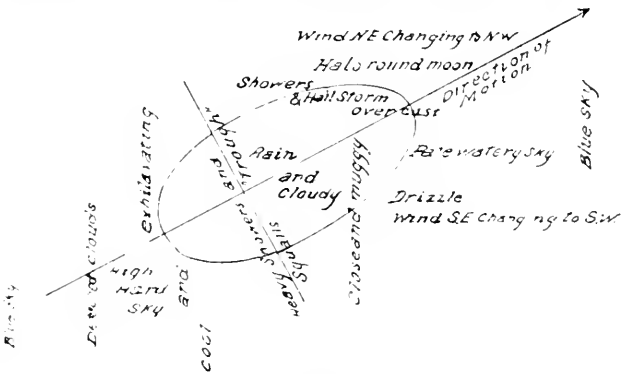


FIG. 58.

right angles to the direction of motion is known as the line of the "trough."

The broadest feature of the weather in an average cyclone consists of an area of rain near the center surrounded by a ring of cloud, but both rain and cloud extend farther to the front than to the rear of the center. When, however, examining the nature of the cloud and rain as well as the general appearance of the sky, it is found that the cyclone is divided into two well-marked halves by the line of the "trough." The front may be further divided into right or southeast, and left or northeast fronts which, though they have much in common, are sufficiently different to be classified separately.

Coming now to more minute detail, in the left or northeast front when the steepest "Gradients" are somewhere south of the center, the first symptoms of the approach of a cyclone are a halo, with a gradual darkening of the sky until it becomes quite overcast without any appearance of the formation of true clouds; or else light

wisps or barred stripes of cirrus moving sideways, appear in the blue sky, and gradually soften into a uniform black sky of a strato-cumulus type; near the center light ill-defined showers fall from a uniformly black sky, the wind from some point between southeast and northeast blows uneasily, and though the air is cold and chilly there is an oppressive feeling about it. These appearances continue until the barometer commences to rise, when the character of the weather at once begins to alter. In a cyclone, when the steepest "Gradients" are somewhere to the north and east of the center, the general character of the weather is the same as above described, but much more intense. The wind rising at times to a heavy gale, and the ill-defined showers developing into violent squalls.

In the right or southeast front, when the steepest "Gradients" are to some point south of the center, which are the commonest cases, the first symptoms are likewise a gradual darkening of the sky into the well-known pale or watery sky, with muggy, oppressive air; or else, as in the northeast front, wisps of cirrus first appear in the blue sky which gradually becomes heavier and softer until the sky is uniformly overcast with a strato-cumulus type of cloud. Near the center rain usually in the form of a drizzle sets in and the wind from some point between southeast and southwest, vary in force according to the steepness of the "Gradients," drives the cloud and rain before it.

In winter snow takes the place of rain and in the autumn the northeast wind brings with it little flurries of snow.

The line of the "trough" marks the line of heavy showers or squalls, especially the portion on the southern side of the center.

The general character of the west of the depression is a cool, exhilarating feeling in the air, with a high, hard sky of which the tendency is always to break into firm, detached masses of cloud. The rain which occurs near the center is usually in cold, hard, brisk showers or hard squalls, and the general look of the weather presents a marked contrast to the dirty appearance of the weather which characterizes the whole front part of a cyclone. Farther from the center showers or squalls are replaced by simply detached masses of cloud, and finally these disappear leaving a blue sky. The wind from some point between west and north blows gustily.

The whole of the rear of a cyclone partakes of this general character, but the change of weather along the north of the cyclone is not nearly so well marked as along the southern portion.

The motion of cyclones is as a rule from west to east, the general direction being about west-southwest to east-northeast. Occasionally they move north or south, but seldom from east to west.

They may also at times remain stationary for a day or two, but this is rare.

The following indications are printed on every weather map:

When the wind sets in from points between south and southeast and the barometer falls steadily a storm is approaching from the west or northwest, and the center will pass near or north of the observer within 12 or 24 hours, with wind shifting to northwest by way of southwest and west.

When the wind sets in from points between east and northeast and the barometer falls steadily a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 or 24 hours, with wind shifting to northwest by way of north.

The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

B. *The anticyclone.*—The distribution of pressure in an anticyclone is almost the reverse of that in a cyclone. It consists of a central area of high pressure from which the pressure gradually decreases on all sides. The "Gradients" are generally very slight so that the winds, which blow around the center in a clockwise direction, are very light. Unlike a cyclone, no very definite description of the weather can be given: in fact, almost any type of weather may be found in an anticyclone except strong winds; heavy rain is also infrequent. On the whole, the weather is fine, but in winter periods of dull, cloudy weather often accompany an anticyclone. On the other hand, days with cloudless skies, and keen, frosty weather in winter or hot weather in summer, frequently occur in anticyclones. Unlike cyclones, they have no general direction of motion, but move very slowly and in any direction. They frequently remain stationary for several days together. In the colder months anticyclones are very frequently accompanied by fog.

C. *Secondary depressions.*—On the outside of a cyclone irregularities in the isobars frequently occur. These may be mere kinks in the isobars, or they may be well marked and have an independent area of low pressure. A very common form is for the isobars to have approximately the shape of a V, such cases being known as V depressions. The secondaries travel around the main depression in the same direction as do the winds, viz, anticlockwise.

The weather in these secondaries varies according to whether they are well marked or not. Where only a small kink occurs, only cloudy skies and temporary rain may be produced, but if they are well marked and the "Gradients" are steep the winds may become very strong and the weather very bad.

In a secondary depression of average intensity the sequence of weather is as follows:

As the secondary approaches, the weather is similar to that in the right front of a cyclone; as the secondary passes, the barometer suddenly begins to rise and there is frequently a heavy squall, as in the "trough" of a cyclone, and the wind suddenly veers to a more northerly quarter.

On the side away from the center of the main cyclone the winds are generally very strong, but between the secondary and the main depression they are light. In the rear of a secondary the weather is similar to that in the rear of a cyclone.

D. *The wedge.*—It frequently occurs that a series of cyclones pass across the country in a continuous succession. Between two of these cyclones the isobars will be roughly V-shaped, but in this case with the highest pressure within the V. These are times of brilliantly fine weather, cloudless skies, and clear atmosphere, but as another cyclone is approaching they last only a short time.

E. *Line squalls.*—It has been said that as the "trough" of a cyclone passes there is frequently a heavy squall. This is generally of the type known as a "line squall." Such a squall stretches in a line for a long distance across the country and may be as much as 500 miles in length. The squall moves in a direction approximately at right angles to its length with a velocity of between 30 and 50 miles an hour. The breadth of the squall is usually narrow, so that it does not last long—generally from half an hour to two hours. The squall gives no sign of its approach, except that if the sky is fairly cloudless a long line of well-marked cumulus may be seen in the distance, gradually coming nearer. As the squall reaches the observer the wind suddenly increases (or occasionally increases slightly and then suddenly decreases) and at the same time the direction suddenly changes to a more northerly quarter.

The barometer generally shows a small, sudden rise, and the temperature always suddenly falls. Heavy rain and frequent hail, with sometimes thunder, set in at once. The whole squall is of a violent nature and it may do considerable damage. This phenomenon seems to be caused by the sudden inrush of a cold current of air from some northerly quarter, which forces the warmer air in front of it to ascend. As these squalls give no warning of their approach, and as they are very violent, they are of a particularly dangerous nature. They are to be expected when the "trough" of a depression passes, and especially in a V, or secondary. After one squall has passed, others frequently follow in the next few hours. These "line squalls" may also occur at times in conditions that

would be expected to give only a moderate westerly or southwesterly wind. An observer can only forecast these phenomena when he is in possession of information that a squall has passed certain points and is traveling in his direction.

F. *Fog.*—True fog (clouds on the surface of the earth are not true fog) on land is only formed when there is little wind and when the sky is cloudless. During the day the air is warm and takes up water vapor. On a calm, cloudless evening the ground is cooled by outward radiation and the air near the ground is also cooled. This cold air being heavier flows down the sides of hills and mixes with the warm, moist air over the valleys, which is thereby cooled. The cooling so produced may be sufficient to cause some of the water vapor to condense, and fog is formed. If there is much wind the air is kept stirred up and no cold air is formed. If, on the other hand, the sky is cloudy, the ground is not cooled by radiation, so that in this case no fog is formed.

G. *Conditions of the atmosphere affecting aviation.*—The available knowledge of the upper air is still rather small, but some information has been obtained which is of use to aviators. If it is required to ascertain what the wind is at a height above the ground, there are several methods by which this information may be obtained.

First, by sending up a small balloon which drifts along with the velocity of the wind at the height it has reached. The balloon is observed by theodolites, and the velocity and direction of the wind at any height can be calculated accurately. This, however, is an elaborate method and takes considerable time.

Secondly, some information may be obtained by observing the motion of the clouds. From these the direction of the wind at their level may be accurately gauged. It must, however, be remembered that the height of the clouds can not definitely be fixed without suitable instruments, and therefore the velocity is only very approximate. Nevertheless, a rough idea may be obtained by noting whether the clouds are moving quickly or slowly. The lower the clouds are the faster they "appear" to move.

Thirdly, an estimate of the upper wind may be obtained from a daily weather map by calculating the "Gradient" wind. At a height of a thousand feet or more the "Gradient" wind is found to agree very well with the winds at those heights as found by means of kites or pilot balloons.

Fourthly, it is possible to estimate the upper wind from the known surface wind at the time. It is nearly always found that for the first 1,000 or 2,000 feet above the surface the velocity increases

directly as the "height above sea level." Hence, if at a place 500 feet above sea level the surface wind were 15 miles per hour, the velocity of 500 feet above the "surface" (i. e., 1,000 feet above sea level) would be expected to be 30 miles per hour; and at 1,000 feet above the "surface" (i. e., 1,500 feet above sea level), 45 miles per hour. This regular increase in velocity goes on until the "Gradient velocity" is reached, after which the wind generally remains almost constant, but may increase or decrease. In the case of easterly winds there is very frequently a decrease at higher altitudes. The direction of the wind a few thousand feet up is slightly changed in a clockwise direction from that of the surface wind, i. e., if the surface wind were south the upper wind might be expected to be south-southwest or southwest. A table of changes in velocity and direction which are the results of observation is given in the Appendix.

A rough rule for the pilot is this: The wind at a flying height may be expected to be double that on the airdrome, and to have changed two points to the right of the direction in which one should leave the airdrome.

It is a well-known fact that the wind is frequently stronger in the day than at night. This is nearly always the case except in rough weather. At sea the effect is not so marked. The decrease at night, however, only takes place at the surface. At a height of from 1,000 to 2,000 feet the wind is stronger at night than in the day. The cause of the surface decrease in velocity at night seems to be the formation of a shallow layer of air on the ground, which does not take part in the general movement of the air.

While the velocity of the wind increases with height, the gustiness almost invariably falls off, so that the wind is more steady above than at the surface. No definite rule can be given about the relation of gustiness and height.

Allied with gusts are "remous" experienced in flying. These may be due to two causes: First, a horizontal gust suddenly striking the airplane and causing a temporary change in its velocity through the air: this will produce a momentary change in the lift. Secondly, there may be an ascending or descending current, which will make the airplane rise or fall.

These upward or downward currents may be caused either by trees, buildings, the contour of the ground, or they may be due to rising currents of hot air.

Another possible occurrence is for the airplane to pass into a mass of air moving in a different direction to that in which it had been

before. This also causes a temporary change in the speed through the air, but this last cause is not a common occurrence.

Clouds.—The water vapor in the air is chiefly supplied by the evaporation from the surface of oceans, lakes, etc. The air can only hold a certain amount of water vapor. Hot air holds more than cold, so that if the temperature of warm air which is saturated with water vapor be lowered the result is the formation of fog clouds, rain, or snow. The formation of these is facilitated by the presence

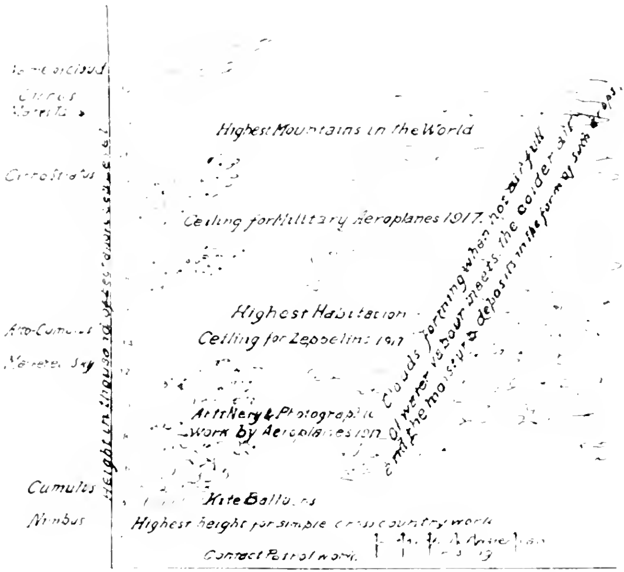


FIG. 59.

of dust in the atmosphere around which the particles of water can form.

The warm, moist air near the surface of the earth rises, meets the colder air at higher levels, which causes the formation of clouds out of which rain falls.

The highest clouds are the cirrus, which occur at about 30,000 feet. They are composed of particles of snow and ice. The sun can shine through them and they appear delicate, fibrous, and hair-like. These clouds are sometimes called "Mares tails."

Below at about 20,000 feet are the cirro-cumulus clouds, which consist of detached, white, globular masses. They form during the hottest months of the year, when the air is still, and foretell the breaking up of an anticyclone.

At about 16,000 feet is a formation of cloud, sometimes spoken of as the "Mackerel sky." This is a calm-weather cloud and is often observed apparently motionless for some time.

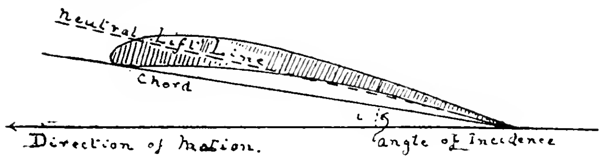


FIG. 60.

Below this are the clouds formed by the ascending currents of air which may be met with from close to the ground to about 10,000 feet.

XVI. THEORY OF FLIGHT.

Air has weight inertia and momentum. It therefore obeys Newton's laws and resists movement. It is that resistance or reaction which makes flight possible.

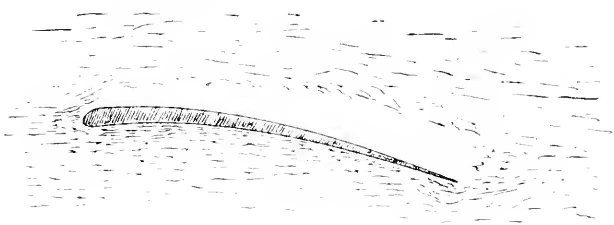


FIG. 61.

Flight is secured by driving through the air a surface inclined upward and toward the direction of motion. This surface may be either straight or curved.

Chord.—The chord is, for practical purposes, taken to be a straight line from the leading edge of the surface to its trailing edge.

For purposes of considering the lift of a surface this line is drawn too low. The neutral lift line, for a curved surface, is found by means of wind tunnel research and it varies with the differences n the camber of surfaces. This neutral lift line is above the "chord" of the surface.

In order to secure flight the inclination of the surface must be such that the neutral lift line makes an angle with and above the

line of motion. If it is coincident with the line of motion there is no lift. If it makes an angle with the direction of motion and below it then there is a pressure tending to force the surface down.

Angle of incidence.—This angle is defined as the angle the chord makes with the direction of motion. This is a bad definition, as it leads to misconception and is described thus chiefly so that the incidence of a plane can be measured easily when rigging an airplane.

The angle of incidence for the purposes of considering flight is best described as the angle the neutral lift line makes with the direction of motion relative to the air. It will be no good giving a practical rigger this definition, as he would be unable to find the neutral lift line and he would probably not know the direction of motion relative to the air, whereas, he can easily put the machine

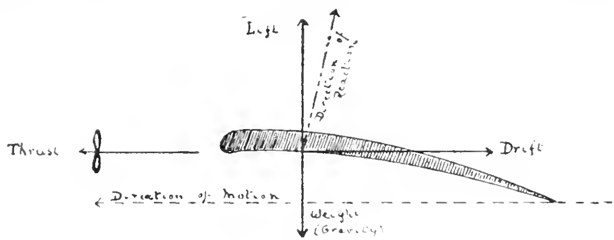


FIG. 62.

with the thrust horizontal and measure how high the leading edge is above the trailing edge. This is explained because there are certain machines which are described as having a negative angle of incidence on the main plane, and one might get the idea that these machines lift, although the angle is negative. This is not so because the neutral lift line must always be above the line of motion. These remarks only apply to cambered surfaces. In the case of flat surfaces the neutral lift line coincides with the chord. Flat lifting surfaces are never used in a machine.

A surface acts upon the air in the following manner:

As the bottom surface meets the air it compresses it and accelerates it downward. As a result of this definite action there is, of course, an equal and opposite reaction upward.

The top surface in moving forward tends to leave air behind it, thus creating a semivacuum or rarified area over the top of the surface. Consequently, the pressure of air on the top of the surface is decreased, thus assisting the action below to lift the surface upward.

The reaction increases approximately as the square of the velocity. Approximately three-fifths of the reaction is due to the decrease of

density on the top of the surface, and only some two-fifths is due to the upward reaction secured by the action of the bottom surface upon the air. A practical point in respect to this is that in the event of the fabric covering the surface getting into bad condition it is more likely to strip off the top than off the bottom.

The value of the reaction on an inclined surface is given by the equation

$$R=KSV^2i$$

where R is total reaction; K is a coefficient which varies with various wing curves; S is the surface of the aerofoil; V is the velocity of the surface through the air; i the angle at which the aerofoil meets the stream of air measured in. Radians and this angle in practical flight is always very small.

This formula is inserted here, as it is the fundamental formula of flight.

The direction of the reaction is, at efficient angles of incidence, approximately at right angles to the neutral line of the surface, and it is, in considering flight, convenient to divide it into two component parts or values thus:

1. The vertical component of the reaction, i. e., lift which is opposed to gravity, i. e., the weight of the airplane.

2. The horizontal component, i. e., drift (sometimes called resistance), to which is opposed the thrust of the propeller.

The direction of the reaction is, of course, the resultant of the forces lift and drift. The lift is the useful part of the reaction. The drift is far from useful and must be overcome by the thrust in order to secure the necessary velocity to produce the requisite lift for flight.

Drift.—The drift of the whole airplane (we have considered only the lifting surface heretofore) may be conveniently divided into three parts, as follows:

Active drift, which is the drift produced by the lifting surfaces.

Passive drift, which is the drift produced by all the rest of the airplane, the struts, wires, fuselage, landing gear, etc., all of which is known as the "detrimental surface."

Skin friction, which is the drift produced by the friction of the air with roughness of surface. The latter is practically negligible, having regard to the smooth surface of the modern airplane, and its comparatively slow velocity compared with, for instance, the velocity of a propeller blade.

LIFT-DRIFT RATIO.

The importance of lift to drift is known as the lift-drift ratio and is of paramount importance, for it expresses the "efficiency" of the airplane (as distinct from the engine and propeller). A knowledge of the factors governing the lift-drift ratio is, as will be seen later,

an absolute necessity to anyone responsible for the rigging of an airplane and the maintenance of it in an efficient and safe condition.

These factors are as follows:

Velocity.—The greater the velocity the greater the proportion of drift to lift, and consequently the less the efficiency. Considering the lifting surfaces only, both the lift and (active) drift, being component parts of the reaction, increase in the same proportion (as the square of the velocity) and the efficiency remains the same at all speeds. However, considering the airplane as a whole, we must remember the passive drift. This also increases as the square of the velocity, but there is no attendant lift. This passive drift adds itself to the active drift and results in increasing the proportion of total drift to lift.

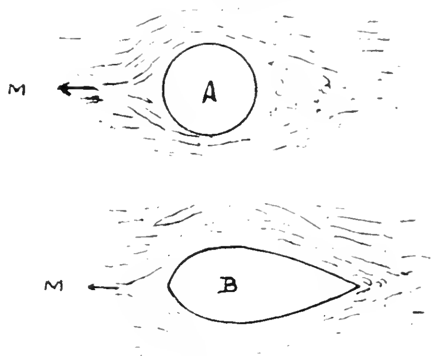


FIG. 63.

But for the increase in passive drift the efficiency of the airplane would not fall with increasing velocity, and it would be possible by doubling the thrust to approximately double the speed or lift.

This can never be done, but every effort is made to decrease the passive drift by "stream lining," i. e., by giving all "detrimental" parts of the airplane a form by which they will pass through the air with the least possible drift. The fuselage, struts, wires, etc., are all "stream lined" as much as possible. In the case of a certain well-known type of airplane the replacing of the ordinary wires by "stream-lined" wires added over 5 miles an hour to the flight speed.

"Head resistance" is a term often applied to passive drift, but it is apt to convey a wrong impression, as the drift is not nearly so much the result of the head or forward part of struts, wires, etc., as it is of the rarified area behind.

The above illustrates the flow of air around two objects moving in the direction of the arrow.

In the case of A you will note that the rarefied area behind the object is very considerable, whereas in the case of B the air flows around it in such a way as to meet very closely in the rear of the object, thus decreasing the rarefied area.

The greater the rarefied area the less the density, and consequently the less the pressure of air upon the rear of the object. This means that it will require more thrust to overcome this backward pressure.

The "fineness" of the stream-line shape, i. e., the proportion of length to width, is determined by the velocity—the greater the velocity the greater the fineness. The best degree of fineness for any given velocity is found by means of wind-tunnel research.

The practical application of all this is, from a rigging point of view, the importance of adjusting all stream-line parts to be dead on in the line of flight.

Angle of incidence.—The most efficient angle of incidence varies with the thrust at the disposal of the designer, the weight to be carried, and the climb-velocity ratio desired.

The best angles of incidence for these varying factors are found by means of wind-tunnel research and practical trial and error. Generally speaking, the greater the velocity the smaller should be the angle of incidence in order to preserve a clean stream-line shape and prevent the formation of a rarefied area and the formation of eddies. Should the angle be too great for the velocity then the rarefied area over the top of the surface becomes of irregular shape with attendant turbulent eddies. Such eddies possess no lift value since it has taken power to produce them; they represent drift and adversely affect the lift-drift ratio. Also too great an angle for the velocity will result in the under side of the surface tending to compress the air against which it is driven rather than accelerate it downward, and that will tend to produce drift rather than the upward reaction or lift.

From a rigging point of view one must presume that every standard airplane has its lifting surface set at the most efficient angle, and the practical application of all this is in taking the greatest possible care to rig the surface at the correct angle and to maintain it at such an angle. Any deviation will adversely affect the lift-drift ratio, i. e., the efficiency.

Chamber.—

The lifting surfaces are cambered, i. e., curved, in order to decrease the horizontal component of the reaction, i. e., the drift.

The bottom camber: If the bottom of the surface were flat every particle of air meeting it would do so with a shock, and such shock would produce a very considerable horizontal reaction or drift. By curving the surface such shock is diminished and the curve should be such as to produce a uniform (not necessarily constant) acceleration and compression of the air from the leading edge to the trailing edge. Any unevenness in the acceleration and compression of the air produces drift.

The top camber: If this was flat it would produce a rarefied area of irregular shape. The bad effect of this upon the lift-drift ratio has already been explained. The top surface is then curved to produce a rarefied area the shape of which shall be as stream-line and free from attendant eddies as possible.

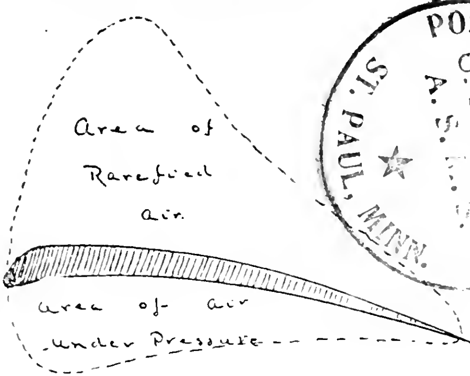


FIG. 64.

The camber varies with the angle of incidence, the velocity, and the thickness of the surface. Generally speaking, the greater the velocity the less the camber and angle of incidence. With infinite velocity the surface will be set at no angle of incidence (the neutral lift line coincident with the direction of motion relative to the air),

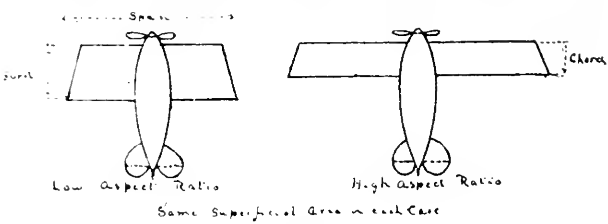


FIG. 65.

and would be top and bottom of pure stream-line form, i. e., of infinite fineness. This is, of course, carrying theory to an absurdity, as the surface would then cease to exist.

The best cambers for varying velocities, angles of incidence, and thicknesses of surface are found by means of wind-tunnel research.

The practical application of all this is in taking the greatest care to prevent the surface from becoming distorted and thus spoiling the camber and consequently the lift-drift ratio.

The advantages of a cambered plane over a flat surface are these:

1. A cambered plane continues to lift when the chord is parallel to the line of flight.

2. The total lift is much greater than that of a flat plane of equal surface.

3. The resistance of a cambered plane in relation to its lift is much less than that of a flat surface.

4. The top and bottom cambers can be made of different shapes so that each will give the maximum lift.

5. This enables suitable spars and bracing to be placed inside the surface without loss of efficiency.

Aspect ratio.—

This is the proportion of span to chord. Thus, if the span is for instance 50 feet and the chord 5 feet, the surface would be said to have an aspect ratio of 10 to 1.

If a flat surface is acted on by a stream of air at right angles to this surface the shape does not very much matter. But when this surface is inclined to the direction of motion of the air the shape makes a great difference.

For a given velocity and a given area of surface, the higher the aspect ratio the greater the reaction. It is obvious, I think, that the greater the span, the greater the mass of undisturbed air engaged, and, as already explained, the reaction is partly the result of the mass of air engaged. The word "undisturbed" is used, for otherwise it might be argued that whatever the shape of the surface, the same mass of air would be engaged. The word "undisturbed" makes all the difference, for it must be remembered that the rear part of the under side of the surface engages air most of which has been deflected downward by the surface in front of it. That being so the rear part of the surface has not the same opportunity of forcing the air downward (since it is already flowing downward) and securing therefrom an upward reaction as has the surface in front of it. It is therefore of less value for its area than the front part of the surface, since it does less work and secures less reaction, i. e., lift. Again the rarefied area over the top of the surface is most rare toward the front of it, as owing to eddies the rear of such area tends to become denser.

Thus you see that the front part of the surface is the most valuable from the point of view of securing an upward reaction from the air; and so by increasing the proportion of front, or span, to chord, we increase the amount of reaction for a given velocity and area of surface. That means a better proportion of reaction to weight of surface, though the designer must not forget the drift of struts and wires necessary to brace up a surface of high aspect ratio.

Not only that, but provided the chord is not decreased to an extent making it impossible to secure the best camber owing to the thickness of the surface, the higher the aspect ratio the better the lift-drift ratio. The reason of this is rather obscure. It is sometimes advanced that it is owing to the "spill" of air from under the wing tips; with a high aspect ratio the chord is less than would otherwise be the case. Less chord results in smaller wing tips and conse-

FIG. 66.

quently less "spill." This, however, appears to be a rather inadequate reason for the high aspect ratio producing the high lift-drift ratio. Other reasons are also advanced, but they are of such a contentious nature that it is hardly well to go into them here. They are of interest to designers, but not to the same extent to the practical pilot and rigger.

Stagger.—

This is the advancement of the top surface relative to the bottom surface and is not of course applicable to a single surface, i. e., a monoplane. In the case of a biplane having no stagger, there will be "interference" and consequent loss of efficiency unless the gap between the top and bottom surfaces is equal to not less than about one and a half times the chord. If less than that the air engaged by the bottom of the top surface will have a tendency to be drawn into the rarefied area over the top of the bottom surface, with the result that the surfaces will not secure as good a reaction as would otherwise be the case.

It is not practicable to have a gap of much more than distance equal to the chord owing to the drift produced by the great length of struts and wires such a large gap would necessitate. By "staggering" the top surface forward, however, it is removed from the action of the lower surface and engages undisturbed air, with the result that the efficiency can in this way be increased by about 5 per cent. Theoretically, the top plane should be "staggered" forward for a distance equal to about 30 per cent of the chord, the exact distance depending upon the velocity and angle of incidence; but this is not always possible to arrange in designing an airplane owing to difficulties of balance, desired position, and view of pilot, observer, etc.

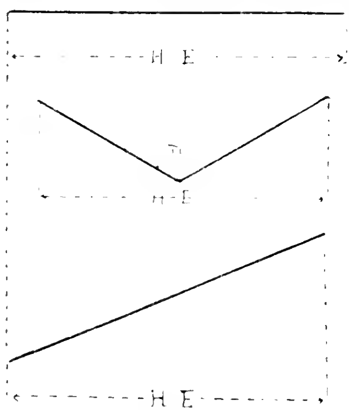


FIG. 67.

Horizontal equivalent.—The vertical component of the reaction, i. e., lift varies as the horizontal equivalent (H. E.) of the surface, but the drift remains the same. Then it follows that if the H. E. grows less the ratio of lift to drift must do the same. The above are front views of three surfaces of equal area.

The top view has it full H. E. and therefore, from the point of view from which we are at the moment considering efficiency, it has its best lift-drift ratio. The two lower views possess the same surface as that of the one above, but one is inclined upward from its center and the other is straight but tilted. For these reasons their H. E.'s are, as illustrated, less than in the case of the first view. That means less vertical lift and the drift remaining the same (for there is the same amount of surface in each) the lift-drift ratio falls.

The margin of power.—This is the power available above that necessary to maintain horizontal flight.

The margin of lift.—This is the height an airplane can gain in a given time starting from a given altitude. As an example, thus—1,000 feet the first minute and starting from an altitude of 500 feet above mean sea level.

The margin of lift decreases with altitude owing to the decrease in the density of the air which adversely affects the engine. Provided the engine maintains its impulse with altitude, then, if we

ignore the problem of the propeller, the margin of lift would not disappear. Moreover, greater velocity for a given power would be secured at a greater altitude, owing to the decreased density of air to be overcome.

At the present time machines are being designed to be most efficient in air of decreased density and attention is being paid to keeping up the power of the engine at a height by means of "blowers" and "supercharges" which increase the charge sucked into a cylinder at a high altitude.

The minimum angle of incidence is the smallest angle at which, for a given power, surface (including detrimental surface) and weight, horizontal flight can be maintained.

The maximum angle of incidence is the greatest angle at which for a given power, surface (including detrimental surface) and weight, horizontal flight can be maintained.

The optimum angle of incidence is the angle at which the lift-drift ratio is highest. In modern airplanes it is that angle of incidence possessed by the surface of the main plane when the axis of the propeller is horizontal.

The best climbing angle is approximately halfway between the maximum and optimum angles.

All present day airplanes are a compromise between climb and horizontal velocity.

Essentials for maximum climb.—

1. Low velocity, in order to secure the best lift-drift ratio.

2. Having a low velocity, a large surface will be necessary in order to engage the necessary mass of air to secure the requisite lift.

3. Since (*a*) such a climbing machine will move along an upward sloping path, and (*b*) will climb with its propeller thrust horizontal, then a large angle of the main plane relative to the direction of thrust will be necessary in order to secure the requisite angle relative to the direction of motion.

4. The velocity being low then it follows that for that reason also the angle of incidence should be comparatively large.

5. Since such an airplane would be of low velocity and therefore possesses a large angle of incidence, a large camber would be necessary.

The propeller thrust should be always horizontal because the most efficient flying machine (having regard to climb and velocity) has so far been found to be an arrangement of an inclined surface driven by a horizontal thrust—the surface lifting the weight and the thrust overcoming the drift.

This is in practice a far more efficient arrangement than the hellicopter, i. e., the propeller revolving about a vertical axis and producing a thrust opposed to gravity. If when climbing the propeller thrust is at such an angle as to tend to haul the airplane upward, then it is in a measure acting as a hellicopter and that means inefficiency. The reason of a hellicopter being inefficient in practice is due to the fact that, owing to mechanical difficulties, it is impossible to construct within a reasonable weight a

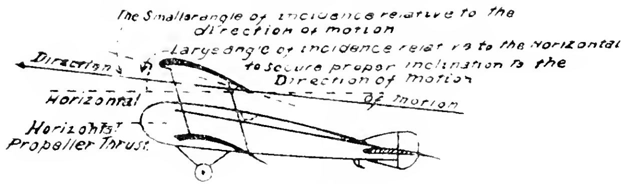


FIG. 68.

propeller of the requisite dimensions. That being so it would be necessary in order to absorb the power of the engine, to revolve the comparatively small surface propeller at an immensely greater velocity than that of the airplane surface. As already explained, the lift-drift ratio falls with velocity on account of the increase in passive drift. This applies to a blade of a propeller, which is nothing but a revolving surface set at an angle of incidence, and which it is impossible to construct without a good deal of detrimental surface near the fuselage.

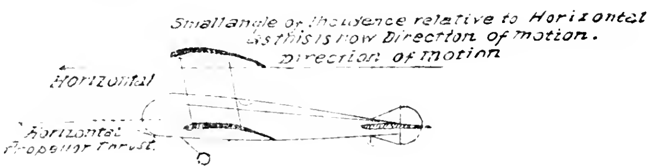


FIG. 69.

Essentials for maximum velocity.—

The following are the essentials for an airplane of maximum velocity for its power, and possessing merely enough lift to get off the ground, but no margin of lift:

1. Comparatively high velocity.

2. A comparatively small surface because, being of greater velocity than the maximum climber, a greater mass of air will be engaged for a given surface and time, and therefore a smaller surface will be sufficient to secure the requisite lift.

3. A small angle relative to the propeller thrust, since the latter coincides with the direction of motion.

4. A comparatively small angle of incidence by reason of the high velocity.

5. A comparatively small camber follows as the result of the small angle of incidence.

It is mechanically impossible to construct an airplane of reasonable weight of which it would be possible to vary the above opposing essentials. Therefore, all airplanes are designed as a compromise between climb and velocity.

As a rule airplanes are designed to have at low altitude a slight margin of lift when the propeller thrust is horizontal. By this means when the altitude is reached where the margin of lift disappears (on account of loss of engine power), and which is, consequently, the altitude where it is just possible to maintain horizontal flight, the airplane is flying with its thrust horizontal and with maximum efficiency (as distinct from engine and propeller efficiency). The margin of lift at low altitude and when the thrust is horizontal should then be such that the higher altitude at which the margin of lift is lost is that altitude at which most of the airplanes' horizontal-flight work is done. That insures maximum velocity when most required.

Unfortunately, when airplanes designed for fighting are concerned the altitude where most of the work is done is that at which both maximum velocity and maximum margin of lift for power are required. At present designers are unable to effect this.

XVII. STABILITY.

Stability is a condition whereby an object disturbed has a natural tendency to return to its first and normal position. For example, a weight suspended by a cord.

Instability is a condition whereby an object disturbed has a natural tendency to move as far as possible away from its first position with no tendency to return. For example, a stick balanced vertically upon the finger.

Natural instability is a condition whereby an object disturbed has no tendency to move farther than it is displaced by the force of the disturbance, and has no tendency to return to its first position.

In order that an airplane may be reasonably controllable, it is necessary for it to possess some degree of stability longitudinally, laterally, and directionally.

Longitudinal stability in an airplane is its stability about an axis transverse to the direction of normal horizontal flight, and without which it would pitch and toss.

Lateral stability is its stability about its longitudinal axis and without which it would roll sideways.

Directional stability is its stability about its vertical axis. and without which it would have no tendency to keep its course.

For such directional stability to exist there must be "in effect" more "keel surface" behind the vertical axis than there is in front of it. By "keel surface" is meant everything which can be seen when looking at an airplane from the side—the sides of the body. landing gear, struts, wires, etc. The words "in effect" are used because the actual area of the "keel surface" in front of the vertical axis may be greater than the actual surface behind this axis; but such surface will be much nearer to the axis so that it has not nearly so much leverage as the surface behind.

The above illustration represents an airplane (directionally stable) flying along a course B. A gust striking it as indicated acts

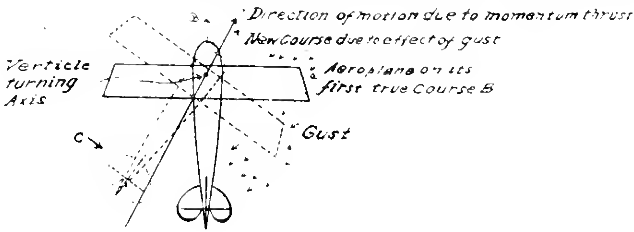


FIG. 70.

upon the greater proportion of "keel surface" behind the turning axis and throws it into a new course. The machine, however, does not travel along this new course, owing to its momentum in the direction B. It travels as long as such momentum lasts in a direction which is the resultant of the two forces—thrust and momentum. But the center line of the airplane is pointing in the direction of the new course; therefore its attitude relative to the direction of motion is more or less sideways, and it consequently receives an air pressure in the direction C. Such pressure acting along the "keel surface" presses the tail back toward the first position, in which the airplane is upon its course B.

This tendency to turn is continually taking place during flight, but in a well-designed airplane such stabilizing movements are, for the most time, so slight as to be imperceptible to the pilot.

If an airplane was not stabilized in this way it would not only be continually trying to leave its course, but it would also possess a dangerous tendency to "nose away" from the direction of the side gusts. In such case the gust shown in the above illustration would turn the airplane around the opposite way a very considerable dis-

tance; and the right wing being on the outside of the turn would travel with greater velocity than the left wing. Increased velocity means increased lift; so that, the right wing lifting, the airplane would turn over sideways very quickly.

Longitudinal stability.—Flat surfaces are longitudinally stable, owing to the fact that with decreasing angles of incidence the center line of pressure (C. P.) moves forward.

The C. P. is a line taken across the surface, transverse to the direction of motion, and about which all the air forces may be said to balance, or through which they may be said to act.

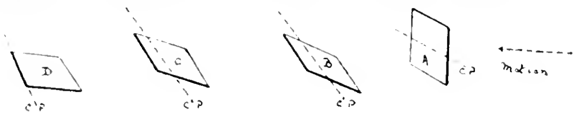


FIG. 71.

Imagine A to be a flat surface, attitude vertical, traveling through the air in the direction of motion M. Its C. P. is then obviously along the exact center line of the surface as illustrated. In B, C, and D, the surfaces are shown with angles of incidence decreasing to nothing, and you will note that the C. P. moves forward with the decreasing angle. The reason the C. P. of an inclined surface is forward of the center of the surface is because the front of the surface does most of the work.

Now, should some gust or eddy tend to make the surface decrease the angle, i. e., dive, then the C. P. moves forward and pushes the

FIG. 72.

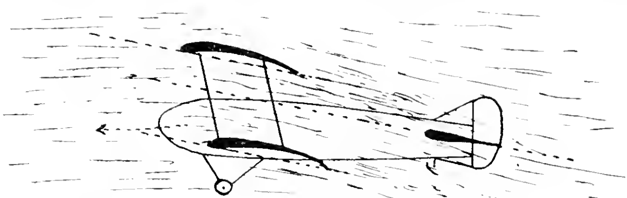
front of the surface up. Should the surface tend to assume too large an angle, then the reverse happens—the C. P. moves back and pushes the rear of the surface up. Flat surfaces are then theoretically stable longitudinally. They are not, however, used on account of their poor lift-drift ratio.

As already explained, cambered surfaces are used, and these are longitudinally unstable at those angles of incidence reducing a reasonable lift-drift ratio, i. e., at angles below about 12°.

A is a cambered surface, attitude approximately vertical, moving through the air in the direction M. The C. P. coincides as before with the transverse center line of the surface. With decreasing

angles down to angles of about 30° the C. P. moves forward as in the case of flat surfaces; but the angles above 30° do no interest us, since they produce a very low ratio of lift to drift.

Below angles of about 30° (see C) the dipping front part of the surface assumes a negative angle of incidence resulting in the downward air pressure D and the more the angle of incidence is decreased, the greater such negative angles and its resultant pressure D. Since the C. P. is the resultant of all the air forces, its position is naturally affected by D, which causes it to move backward. Now should some gust or eddy tend to make the surface decrease its angle of incidence, i. e., dive, then the C. P. moving backward and pushing up the rear of the surface, causes it to dive more. Should the surface tend to assume too large an angle then the reverse happens; the pressure D decreases with the result that the C. P. moves forward



Tail surface engaging air at less angle of incidence than main surface although fixed to aeroplane at same angle.

FIG. 73.

and pushes up the front of the surface thus increasing the angle still farther, the final result being a "tail slide."

It is therefore necessary to find a means of stabilizing the naturally unstable cambered surface. This is usually secured by means of a stabilizing surface fixed some distance in the rear of the main surface, and it is a necessary condition that the neutral lift lines of the two surfaces, when projected to meet each other, make a dihedral angle. In other words, the rear stabilizing surface must have a lesser angle of incidence than the main surface—certainly not more than one-third of that main surface. This is known as the longitudinal dihedral.

The tail plane is sometimes mounted upon the airplane at the same angle as the main surface, but in such cases, it attacks air which has received a downward direction from the main surface, thus:

The angle at which the tail surface attacks the air (the angle of incidence) is therefore less than the angle of incidence of the main surface.

First, imagine the airplane traveling in the direction of motion, which coincides with the direction of the thrust T. The weight is of course balanced about a C. P., the resultant of the C. P. of the main surface and the C. P. of the stabilizing surface. For the sake of illustration the stabilizing surface has been given an angle of incidence and therefore has a lift and C. P. In practice the stabilizer is often set at no angle of incidence. In such case the proposition

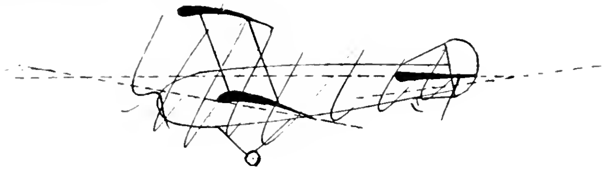


FIG. 74.

remains the same, but it is perhaps a little easier to illustrate it as above.

Now, we will suppose that a gust or eddy throws the machine into the lower position. It no longer travels in the direction of T, since the momentum in the old direction pulls it off that course. M is now the resultant of the thrust and the momentum, and you will note that this results in a decrease in the angle the neutral lift line makes with the direction of motion, i. e., decrease in the angle of incidence and therefor a decrease in the lift.

FIG. 75.

We will suppose that this decrease is 2°. Such decrease applies to both main surface and stabilizer, since both are fixed originally to the airplane.

The main surface, which had (say) 12° angle, has now only 10°, i. e., a loss of one-sixth.

The stabilizer, which had (say) 4° angle, has now only 2°, i. e., a loss of one-half.

The latter has therefore lost a greater proportion of its angle of incidence and consequently its lift than has the main surface. It

must then fall relative to the main surface. The tail falling, the airplane then assumes its first position though at a slightly less altitude.

Should a gust throw the nose of the airplane up then the reverse happens and the airplane will assume its first position, though at a slightly greater altitude.

Do not fall into the widespread error that the angle of incidence varies as the angle of the airplane to the horizontal. It varies "with" such angle, but not "as" anything approaching it. Remember that the stabilizing effect of the longitudinal dihedral lasts only as long as there is momentum in the direction of the first course.

These stabilizing movements are taking place all the time, even though imperceptible to the pilot.

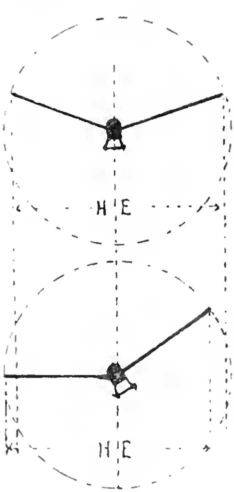


Fig. 76.

The gyroscopic action of a rotary engine will affect the longitudinal stability when an airplane is turned to the right or left. When a right-hand rotary engine is fitted in a tractor machine the nose of the airplane will rise when it is turned to the left and will fall when it is turned to the right. In modern airplanes this tendency is not sufficiently important to bother about except in the matter of spiral descents.

Lateral stability is far more difficult for the designer to secure than is longitudinal or directional stability. Some degree of lateral stability may be secured by means of the lateral dihedral, i. e., the upward inclination of the surface toward its wing tips, thus:

Imagine the top "V" to be the front view of a surface flying away from you. The horizontal equivalent (H. E.) of the left wing is the same as that of the right wing. Therefore, the lift of one wing is equal to the lift of the other, and the weight being situated always in the center is balanced.

If some movement of the air causes the surface to tilt sideways then you will note that the H. E. of the left wing increases and the H. E. of the right wing decreases. The left wing, having the greatest lift, rises; and the surface assumes its first and normal position.

Unfortunately, however, the righting effect is not proportional to the difference between the right and left H. E.'s.

In the case of A the resultant direction of the reaction of both wings is opposed to the direction of gravity or weight. The two

forces, R. R. and gravity, are then evenly balanced and the surface is in a state of equilibrium.

In the case of B you will note that the resultant reaction is not directly opposed to gravity. This results in the appearance of M, a side pressure, and so the resultant direction of motion of the airplane is no longer directly forward, but is along a line the resultant of the thrust and M. In other words, it is while flying forward at the same time moving sideways in the direction of M.

In moving sideways the "keel surface" receives, of course, a pressure from the air equal and opposite to M. Since such surface is greatest in effect toward the tail then the latter must be pushed sideways. That causes the airplane to turn; and the highest wing being on the outside of the turn it has a greater velocity than the lower wing. That produces greater lift and tends to tilt the airplane

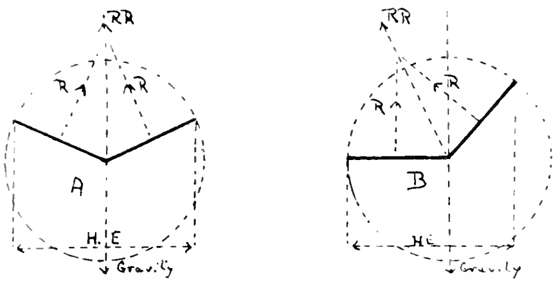


FIG. 77.

still more. Such tilting tendency is, however, opposed by the difference of the H. E.'s of the two wings.

It then follows that for the lateral dihedral angle to be effective such angle must be large enough to produce when the airplane tilts a difference in the H. E.'s of the two wings, which difference must be sufficient not only to oppose the tilting tendency due to the airplane turning, but sufficient also to force the airplane back to its original position of equilibrium.

The above should make it clear that the lateral dihedral is not quite so effective as would appear at first sight. Some designers, indeed, prefer not to use it since its effect is not very great and since it must be paid for in loss of H. E. and consequent loss of lift, thus decreasing the lift-drift ratio, i. e., the efficiency. Also it is sometimes advanced that the lateral dihedral increases the "spill" of air from the wing tips and that this adversely affects the lift-drift ratio.

The disposition of the "keel surface" affects the lateral stability. It should be, in effect, equally divided by the longitudinal axis of the airplane. If there is an excess of "keel surface" above or below

such axis, then a side gust striking it will tend to turn the airplane over sideways.

The position of the center of gravity affects lateral stability. If too low it produces a pendulum effect and causes the airplane to roll sideways.

If too high it acts as a stick balanced vertically would act. If disturbed it tends to travel to a position as far as possible from its original position. It would then tend, when moved, to turn the airplane over sideways and into an upside-down position.

From the point of view of lateral stability the best position for the center of gravity is one a little below the center of drift. This produces a little lateral stability without any marked pendulum effect.

Propeller torque affects lateral stability. An airplane tends to turn over sideways in the opposite direction to that in which the propeller revolves.

This tendency is offset by increasing the angle of incidence (and consequently the lift) of the side tending to fall; and it is always

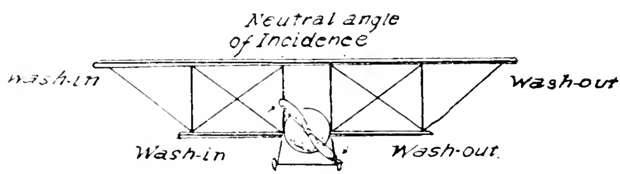


FIG. 78.

advisable, if practical considerations allow it, to also decrease the angle upon the other side an equal amount. In that way it is not necessary to depart so far from the normal angle of incidence at which the lift-drift ratio is highest.

Wash in is the term applied to the increased angle.

Wash out is the term applied to the decreased angle.

Both lateral and directional stability may be improved by washing out the angle of incidence on both sides of the surface.

The decreased angle decreases the drift and therefore the effect of gusts upon the wing tips, which is just where they have the most effect upon the airplane, owing to the distance from the turning axis.

The wash out also renders the ailerons more effective, as, in order to operate them it is not then necessary to give them such a large angle of incidence as would otherwise be required.

The less the angle of incidence of the ailerons the better their lift-drift ratio, i. e., their efficiency. For the same amount of movement therefore the ailerons are more efficient when attached to the surface with washed out angle of incidence.

The advantages of wash in must of course be paid for with some loss of lift, as the lift decreases with the decreased angle.

Banking.—An airplane turned off its course to right or left does not at once proceed along its new course. Its momentum in the direction of its first course causes it to travel along a line the resultant of such momentum and the thrust. In other words, it more or less skids sideways and away from the center of the turn. Its lifting surfaces do not then meet the air in their correct attitude, and the lift may fall to such an extent as to become less than the weight, in which case the airplane must fall. This bad effect is minimized by "banking," i. e., tilting the airplane sideways. The bottom of the lifting surface is in that way opposed to the air through which it is moving in the direction of the momentum and receives an opposite air pressure. The rarified air over the top of the surface is rendered still more rare and this of course assists the air pressure in opposing the momentum.

The velocity of the "skid" or sideways movement is then only such as is necessary to secure an air pressure equal and opposite to the centrifugal force of the turn. The sharper the turn, the greater the effect of the centrifugal force, and therefore the steeper should be the "bank."

The position of the center of gravity effects banking. A low C. G. will tend to swing outward from the center of the turn, and will cause the airplane to bank—perhaps too much, in which case the pilot must remedy matters by operating the ailerons.

A high C. G. also tends to swing outward from the center of the turn. It will tend to make the airplane bank the wrong way, and such effect must be remedied by means of the ailerons.

The pleasantest machine from a banking point of view is one in which the C. G. is a little below the center of drift. It tends to bank the airplane the right way for the turn and the pilot can, if necessary, perfect the bank by means of the ailerons.

The disposition of the "keel surface" affects banking. It should be, in effect, evenly divided by the longitudinal axis. An excess of "keel surface" above the longitudinal surface will when banking receive an air pressure, causing the airplane to bank perhaps too much. An excess of "keel surface" below the axis has the reverse effect.

Side slipping.—This usually occurs as a result of overbanking. It is always the result of the airplane tilting sideways and thus decreasing the horizontal equivalent and therefore the lift of the surface. An excessive bank or sideways tilt results in the H. E. and therefore the lift becoming less than the weight, when of course, the airplane must fall, i. e., side slip.

When making a very sharp turn it is necessary to bank very steeply indeed. If at the same time the longitudinal axis of the airplane remains approximately horizontal then there must be a fall and the direction of motion will be the resultant of the thrust and the fall, as illustrated in sketch A. The lifting surfaces and the controlling surfaces are not then meeting the air in the correct attitude, with the result that in addition to falling the airplane will probably become quite unmanageable.

The pilot, however, prevents such a state of affairs from happening by "nosing down," i. e., by operating the rudder to turn the nose of the airplane downward and toward the direction of motion a

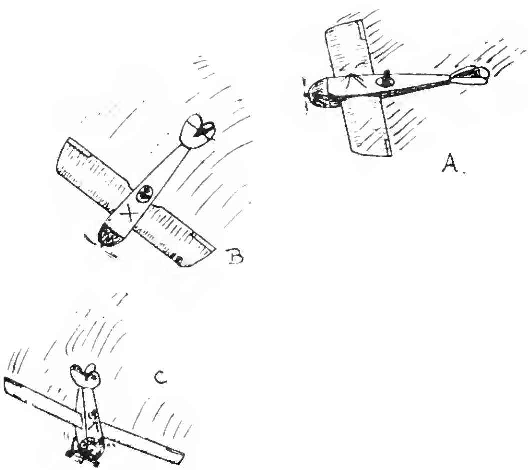


FIG. 79.

illustrated in sketch B. This results in the higher wing which is on the outside of the turn traveling with greater velocity, and therefore securing a greater reaction than the lower wing, thus tending to tilt the airplane over still more. The airplane may be now almost upside down, *but* its attitude relative to the direction of motion is correct and the controlling surfaces are all of them working efficiently. The recovery of a normal attitude relative to the earth is then made as illustrated in sketch C by gently pulling back the elevator control.

The pilot must then learn to know just the angle of bank at which the margin of lift is lost, and, if a sharp turn necessitates banking beyond that angle, he must "nose down." In this matter of banking

and "nosing down" and indeed regarding stability and control generally, the golden rule for all but very experienced pilots should be:

"Keep the airplane in such an attitude that the air pressure is always directly in the pilot's face."

The airplane is then always engaging the air as designed to do so, and both lifting and controlling surfaces are acting efficiently.

Spinning.—A spin is due primarily to the loss of flying speed. It is quite different from a quick turn of small radius. The usual form of spin is for the machine to come down at an angle of about 60° with the tail turning rapidly, and the angle may become steeper and steeper. When this happens the attitude of the lifting surfaces to the direction of motion is too great, and there is a greater pressure trying to collapse the wings than there ought to be.

Owing to the small radius of such a spiral the mass of the airplane may gain a rotary momentum greater in effect than the air pressure of the "keel surface" or controlling surfaces opposed to it; when once such a condition occurs it is difficult to see what can be done by the pilot to remedy it.

In this connection every pilot of an airplane fitted with a rotary engine should bear in mind the gyroscopic effect of such engines. In the case of such an engine fitted to a tractor machine its effect is to depress the nose if a right-hand turn is made. The sharper the turn the greater such effect.

An effect which may render the airplane unmanageable if the spiral is one of very small radius and the engine is revolving with sufficient speed to produce a material gyroscopic effect. Such gyroscopic effect will, however, assist the pilot to navigate a small spiral if he turns his machine the opposite way. The assistance will only be slight because the engine should of course be throttled down for a spiral descent.

Nearly all machines can be made to spin more or less. Some are harder than others.

In order to get into a spin pull back the control until the machine is almost stalled, then kick the rudder one way or the other and the machine will spin.

To get out of a spin throttle back the engine, put all controls in neutral and then slightly push forward the elevator control.

All controls must be put in neutral to give the machine a chance of regaining flying speed. Any control which is in action increases the drift of the airplane and prevents this.

As machines are not specially designed to take the stresses of a spin, machines should not be spun without the sanction of the designers and testers.

Gliding descent without propeller thrust.—All airplanes are or should be designed to assume their correct gliding angle when the power

and thrust is cut off. This relieves the pilot of work, worry, and danger should he find himself in a fog or cloud. The pilot, although he may not realize it, maintains the correct attitude of the airplane by observing its position relative to the horizon. Flying into a fog or cloud, the horizon is lost to view, and he must rely upon his instruments: (1) The compass for direction; (2) an inclinometer, mounted transversely to the longitudinal axis, for lateral stability; and (3) an inclinometer mounted parallel to the longitudinal axis, or the air speed indicator which will indicate a nose-down position by increase in air speed, and a tail-down position by a decrease.

The pilot is then under the necessity of watching three instruments and manipulating his three controls to keep the instrument indicating longitudinal, lateral, and directional stability. That is a feat beyond the capacity of the ordinary man. If, however, by the simple movement of throttling down the power and the thrust

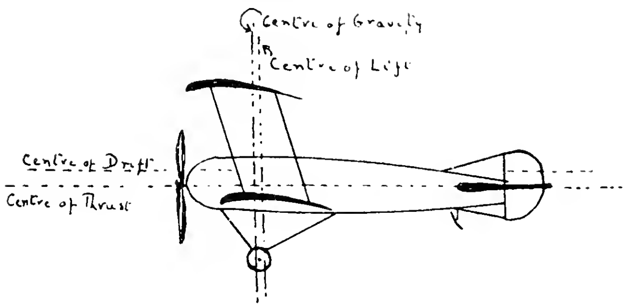


FIG. 80.

he can be relieved of looking after the longitudinal stability he then has only two instruments to watch.

Airplanes are therfore designed, or should be, so that the center of gravity is slightly forward of the center of lift. The airplane is then, as a glider, nose heavy, and the distance the C. G. is placed in advance of the C. L. should be such as to insure a gliding angle producing a velocity the same as the normal flying speed.

In order that this nose-heavy tendency should not exist when the thrust is working and descent not required the center of thrust is placed a little below the center of drift and resistance, and thus tends to pull up the nose of the airplane.

The distance the center of thrust is placed below the center of drift should be such as to produce a force equal and opposite to that due to the C. G. being forward of the C. L.

Looping and upside-down flying.—If a loop is desired it is best to throttle down the engine at a point A when the top of the loop is reached. The C. G. being forward of the C. P. causes the airplane to nose down and assists the pilot in making a reasonably small loop along the course C and in securing a quick recovery. If the engine is not throttled down then the airplane may be expected to follow the course D which results in a longer nose dive than in the case of the course C.

When pulling the machine out of the nose dive a steady and gentle movement of the elevator is necessary. A jerky movement may change the direction of motion so suddenly as to produce dangerous

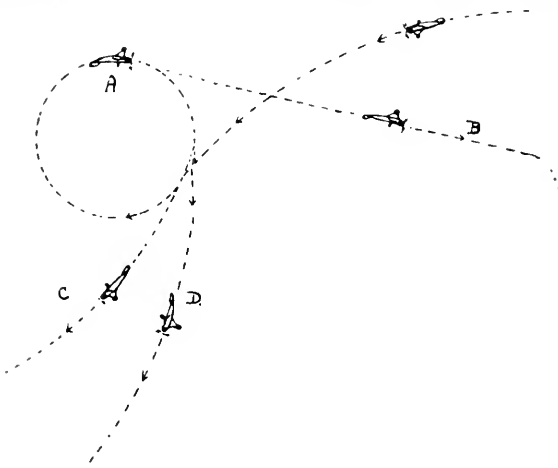


FIG. 81.

air stresses upon the surfaces, in which case there is a possibility to collapse.

If an upside-down flight is desired, the engine may or may not be throttled down at point A. If not throttled down, then the elevator must be operated to secure a course approximately in the direction B. If it is throttled down, then the course must be one of a steeper angle than B or there will be danger of stalling.

To start a loop it is necessary with some machines to push the nose down in order to gather speed. Some machines will go straight over from the horizontal flying position. In any case the elevator should be pulled back gradually until the machine has got very nearly to the position A, when it should be pulled back as far as it will go so

as to bring the machine over top of the loop. As the machine goes over, the rudder must be put over; that is, in a machine which flies with left rudder, the rudder must be put over to the right as the machine goes over the top, otherwise the loop will not be clean. If the elevator control is pulled too roughly the machine will stall before it goes over the top and will not complete the loop.

In machines which will be used for looping and nose diving, and also in high-powered weight-carrying machines, the greatest care must be taken about the tension of the incidence and flying wires. Remember that a machine is designed to take certain stresses when flying. If the bracing wires are tightened to such an extent that they "sing" when vibrated it means that the spars, etc., have a considerable initial strain for which the machine is not designed. All bracing wires should therefore never be tight but should only have the slackness taken out of them and nothing more.

XVIII. NOMENCLATURE.

Aerofoil.

A thin wing-like structure, flat or curved, designed to obtain reaction upon its surfaces from the air through which it moves.

Aileron.

A movable auxiliary surface, used for the control of rolling motion, i. e., rotation about the fore and aft axis.

Aircraft.

Any form of craft designed for the navigation of the air.

Airplane.

A form of aircraft heavier than air, which has wing surfaces for sustentation, with stabilizing surfaces, rudders for steering, and power plant for propulsion through the air. The landing gear may be suited for either land or water use.

Pusher, a type of airplane with the propeller or propellers in the rear of the wings.

Tractor, a type of airplane with the propeller or propellers in front of the wings.

Air-speed meter.

An instrument designed to measure the velocity of an aircraft with reference to the air through which it is moving.

Altimeter.

An instrument mounted on an aircraft to continuously indicate its height above the surface of the earth.

Anemometer.

An instrument for measuring the velocity of the wind or air currents with reference to the earth or some fixed body.

Angle.

Of attack, the angle between the direction of the relative wind and the chord of an aerofoil, or the fore and aft axis of a body.

Critical, the angle of attack at which the lift is maximum.

Gliding, the angle the flight path makes with the horizontal when flying in still air under the influence of gravity alone.

Aspect ratio.

The ratio of spread to chord of an aerofoil.

Axes of an aircraft.

Three fixed lines of reference; usually centroidal and mutually rectangular.

Longitudinal axis, usually parallel to the axis of the propeller, is the principal longitudinal axis in the plane of symmetry. Sometimes called "fore and aft axis."

Vertical axis, the axis perpendicular to the above in the plane of symmetry.

Transverse or lateral axis is the third axis perpendicular to the other two. Sometimes called "athwartship axis."

In mathematical discussions the first of these axes is called the X axis, the second Z axis, and the third the Y axis.

Ballonet.

A small balloon within the interior of a balloon or dirigible for the purpose of controlling the ascent or descent, and for maintaining pressure on the outer envelope to prevent deformation. The ballonet is kept inflated with air at the required pressure, under the control of a blower and valves.

Balloon.

A form of aircraft comprising a gas bag and a car, whose sustentation depends on the buoyance of the contained gas, which is lighter than air.

Captive, a balloon restrained from free flight by means of a cable attaching it to the earth.

Kite, an elongated form of captive balloon fitted with tail appendages to keep it headed into the wind and deriving increased lift due to its axis being inclined to the wind.

Bank.

To incline an airplane laterally, i. e., to rotate it about the fore and aft axis. Right bank is to incline the airplane with the right wing down.

Barograph.

An instrument used to record variations in barometric pressure. In aeronautics the charts on which the records are made are prepared to indicate altitudes directly instead of barometric pressure.

Biplane.

A form of airplane in which the main supporting surface is divided into parts, one above the other.

Body of an airplane.

A structure usually inclosed, which contains in a stream-line housing the power plant, fuel, passengers, etc.

Cabré.

A flying attitude in which the angle of attack is greater than normal; tail down; down by the stern—tail low.

Camber.

The convexity or rise of a curve of an aerofoil from its chord, usually expressed as the ratio of the maximum departure of the curve from the chord as a fraction thereof. Top camber refers to the top surface of an aerofoil, and bottom camber to the bottom surface.

Capacity.

Lifting, the maximum load of an aircraft.

Carrying, excess of the lifting capacity over the dead load of an aircraft, which latter includes structure, power plant, and essential accessories.

Center.

The point in which a set of effects is assumed to be accumulated producing the same effect as if all were concentrated at this point.

Of buoyancy, the center of gravity of the fluid displaced by the floating body.

Of pressure of an aerofoil, the point on the chord of an element of an aerofoil, prolonged if necessary, through which at any instant the line of action of the resultant air force passes.

Of pressure of a body, the point on the axis of a body, prolonged if necessary, through which at any instant the line of action of the resultant air force passes.

Chord.

Of an aerofoil section, a right line tangent to the under curve of the aerofoil section at the front and rear.

Length, the length of the chord is the length of an aerofoil section projected on the chord, extended if necessary.

Controls.

A general term applying to the means provided for operating the devices used to control speed, direction of flight, and attitude of an aircraft.

Dirigible.

A form of balloon the outer envelope of which is of elongated form, provided with a propelling system, car, rudders, and stabilizing surfaces.

Dope.

A general term applied to the materials used in treating the cloth surface of airplane members to increased strength, produce tautness, and act as a filler to maintain air tightness; usually of the cellulose type.

Drag.

The total resistance of motion through the air of an aircraft, i. e., the sum of the drift and head resistance.

Drift.

The component of the resultant wind pressure on an aerofoil or wing surface parallel to the air stream attacking the surface.

Elevator.

A hinged surface for controlling the longitudinal attitude of an aircraft, i. e., its rotation about the athwartship axis.

Engine, right or left hand.

The distinction between a right-hand and a left-hand engine depends on the rotation of the output shaft, whether this shaft rotates in the same direction as the crank or not. A right-hand engine is one in which when viewed from the output shaft end, the shaft is seen to rotate anticlockwise.

Entering edge.

The foremost part of an aerofoil.

Fins.

Small planes on the aircraft to promote stability; for example vertical tail fins, etc.

Flight path:

The path of the center of gravity of an aircraft with reference to the air.

Float:

That portion of the landing gear of an aircraft which provides buoyancy when it is resting on the surface of the water.

Fuselage. (See body.)

Gap:

The distance between the projections on the vertical axis of the entering edges of an upper and lower wing of a biplane.

Glide:

To fly without power.

Head resistance:

The total resistance to motion through the air of all parts of an aircraft not a part of the main lifting surface. Sometimes termed "parasite resistance."

Helicopter:

A form of aircraft whose support in air is derived from the vertical thrust of large propellers.

Inclinometer:

An instrument for measuring the angle made by any axis of an aircraft with the horizontal.

Keelplane area:

The total effective area of an aircraft which acts to prevent skidding or side slipping.

Landing gear:

The understructure of an aircraft designed to carry the load when resting on, or running on, the surface of the land or water.

Leeding edge. (See entering edge.)

Leeway:

The angular deviation from a course over the earth, due to cross currents of wind.

Lift:

The component of the force due to the air pressure of an aerofoil, resolved perpendicular to the flight part in a vertical plane.

Longeron:

A fore-and-aft member of the framing of an airplane body, or of the floats, usually continuous across a number of points of support.

Metacenter:

The point of intersection of a vertical line through the center of gravity of the fluid displaced by a floating body when it is tipped through a small angle from its position of equilibrium and the inclined line which was vertical through the center of gravity of the body when in equilibrium. There is in general a different metacenter for each type of displacement of the floating body.

Monoplane:

A form of airplane whose main supporting surface is disposed as a single wing on each side of the body.

Nacelle. (See body.)

Nose dive:

A dangerously steep descent, head on.

Ornithopter:

A form of aircraft deriving its support and propelling force from flapping wings.

Pilot tube:

A tube with an end open square to the fluid stream, used as a detector of an impact pressure. More usually associated with a concentric tube surrounding it, having perforations normal to the axis for indicating static pressure. The velocity of the fluid can be determined from the difference between the impact pressure and the static pressure. This instrument is often used to determine the velocity of an aircraft through the air.

Propeller:

Disk area of, the total area of the disk swept by the propeller tips.

Right-hand, one in which the helix is right-handed.

Race of, the air stream delivered by the propeller.

Slip of. This term applies to propeller action and is the difference between the actual velocity of advance of an aircraft and the speed calculated from the known pitch of the propeller and its number of revolutions.

Pylon:

A marker of a course.

Rudder.

A hinged or pivoted surface, usually more or less flat or streamlined, used for the purpose of controlling the attitude of an aircraft about its vertical axis when in motion.

Side-slipping.

Sliding toward the inside of a turn. It is due to excessive amount of bank for the turn being made, and is the opposite of skidding.

Skidding.

Skidding sideways in flight away from the center of the turn. It is usually caused by insufficient banking in a turn, and is the opposite of side slipping.

Spread.

The maximum distance laterally from tip to tip of an airplane's wings.

Stability.

The quality of an aircraft in flight which causes it to return to a condition of equilibrium when meeting a disturbance. (This is sometimes called "Dynamical stability.")

Directional, stability with reference to the vertical axis.

Inherent, stability of an aircraft due to the disposition and arrangement of its fixed parts.

Lateral, stability with reference to the longitudinal, or fore and aft axis.

Longitudinal, stability with reference to the lateral, or athwartship axis.

Stabilizer. (See Fins.)

This term usually applies to the fixed horizontal, tail surface of an airplane.

Mechanical, any automatic device designed to secure stability in flight.

Stagger.

The amount of advance of the entering edge of the upper wing of a biplane over that of the lower; it is considered positive when the upper surface is forward.

Stalling.

A term describing the condition of an airplane which from any cause has lost the relative speed necessary for steerage way and control.

Statoscope.

An instrument to detect the existence of a small rate of ascent or descent, principally used in ballooning.

Stream-line flow.

A term in hydromechanics to describe the condition of continuous flow of a fluid, as distinguished from eddying flow where discontinuity takes place.

Stream-line shape.

A shape intended to avoid eddying or discontinuity and to preserve stream-line flow, thus keeping resistance to progress at a minimum.

Strut.

A compression member of a truss frame; for instance, the vertical members of the wing truss of a biplane.

Sweep back.

The horizontal angle between the lateral axis of an airplane and the entering edge of the main planes.

Tail.

The rear portion of the aircraft to which are usually attached rudders, elevators, and fins.

Trailing edge.

The rearmost portion of an aerofoil.

Triplane.

A form of airplane whose main supporting surfaces are divided into three parts superimposed.

Wake gain.

Due to the influence of skin friction, eddying, etc., a vessel in moving forward produces a certain forward movement of the fluid surrounding it. The effect of this is to reduce the effective resistance of the hull, and this effect, due to the forward movement of the wake, is termed the "wake gain." In addition to this effect the forward movement of this body of fluid reduces the actual advance of the propeller through the surrounding medium, thereby reducing the propeller horsepower.

Warp.

To change the form of the wing by twisting it, usually by changing the inclination of the rear spar relative to the front spar.

Wings.

The main supporting surfaces of an airplane.

Wing.

Loading, the weight carried per unit area of supporting surface.

Rib, a fore and aft member of the wing structure, used to support the covering and to give the wing section its form.

Spar, an athwartship member of the wing structure resisting tension and compression.

Yaw.

To swing off the course about the vertical axis, owing to gusts or lack of directional stability.

Angle of, the temporary angular deviation of the fore and aft axis from the course.

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APPENDIX.

TABLE 1.—*Showing fall of barometer with height.*

The height of barometer was taken as 30 inches at mean sea level with temperature 32° F. This approximates to a sounding taken in Belgium.

Feet.	Inches.	Feet.	Inches.	Feet.	Inches.	Feet.	Inches.
1,000......	28.88	6,000......	23.88	11,000.....	19.72	16,000.....	16.30
2,000......	27.80	7,000......	22.99	12,000.....	18.98	17,000.....	15.70
3,000......	26.75	8,000......	22.11	13,000.....	18.27	18,000.....	15.10
4,000......	25.75	9,000......	21.29	14,000.....	17.59	19,000.....	14.54
5,000......	24.79	10,000.....	20.49	15,000.....	16.93	20,000.....	13.99

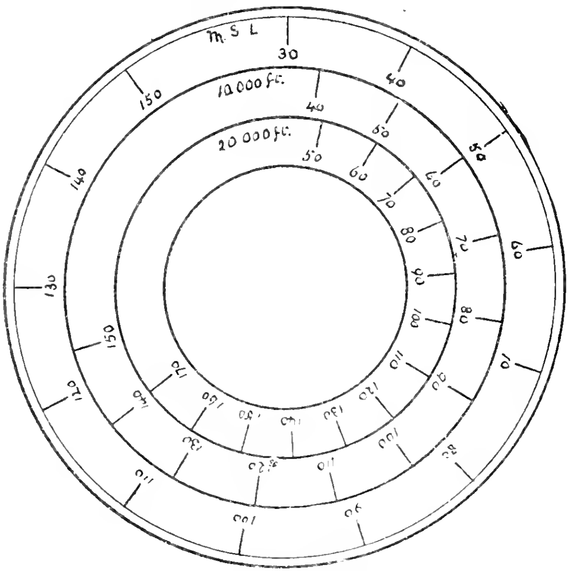

FIG. 82.

TABLE 2.—*Showing approximately the true speed to the air when the air-speed indicator reads 100 miles per hour.*

Feet.	Miles per hour.	Feet.	Miles per hour.	Feet.	Miles per hour.	Feet.	Miles per hour.
1,000......	102	6,000......	112	11,000.....	123.5	16,000.....	135.5
2,000......	104	7,000......	114.5	12,000.....	126	17,000.....	138.3
3,000......	106	8,000......	116.5	13,000.....	128	18,000.....	141
4,000......	108	9,000......	118	14,000.....	130.5	19,000.....	144
5,000......	110	10,000.....	121	15,000.....	133	20,000.....	146

TABLE 3.—*Showing what the graduations on the air-speed indicator represent at 10,000 feet and 20,000 feet.*

Feet.	Graduations.										
	30	40	50	60	70	80	90	100	110	120	130
10,000	36.4	48.5	60.5	72.6	84.8	97	109	121	133	145	157
20,000	51.4	58.6	73.4	88.0	102.5	117	132	146	.....	.....	....

The outside circle above shows the graduations on the air-speed indicator and are taken as correct at mean sea level. The two inner circles are the proper speeds through the air at the heights of 10,000 feet and 20,000 feet. Thus, when flying at 10,000 feet, if the indicator reads 50 miles per hour the true speed is about 60.

TABLE 5.—*Variation of velocity of the wind with height during the daytime.*

[Miles per hour.]

Surface at Upavon.	500 feet.	1,000 feet.	2,000 feet.	3,000 feet.	4,000 feet.	5,000 feet.
5	7	8	8	8	10	13
10	15	18	18	18	19	20
15	21	26	28	29	29	29
20	28	34	37	40	40	40
25	35	43	47	49	50	50

TABLE 6.—*Variation of direction of wind with height.*

Wind veers with increasing height, i. e., upper wind blows from a point to the right (or in a clockwise direction) of that from which the surface wind blows.

The amount of deviation from the direction of the surface wind is given below.

	Surface.	500 feet.	1,000 feet.	2,000 feet.	3,000 feet.	4,000 feet.	5,000 feet.
Deviation to right, in degrees	0	5	10	16	19	20	21

TABLE 7.—*The Beaufort wind scale.*

Beaufort No.	Description of wind.	Mean wind force in pounds per square foot at standard density.	Equivalent velocity, miles per hour.
1	Light breeze	0.01	2
2		.08	5
3		.28	10
4		.67	15
5	Moderate breeze	1.31	21
6		2.3	27
7	Strong wind	3.6	35
8		5.4	42
9	Gale forces	7.7	50
10		10.5	59
11	Storm forces	14.0	68
12	Hurricane	[1] 17.0	[1] 75

[1] Above.